GEOLOGY
and
WATER RESOURCES
of
KLICKITAT COUNTY

Water Supply Bulletin No. 50

August 1979

STATE OF WASHINGTON
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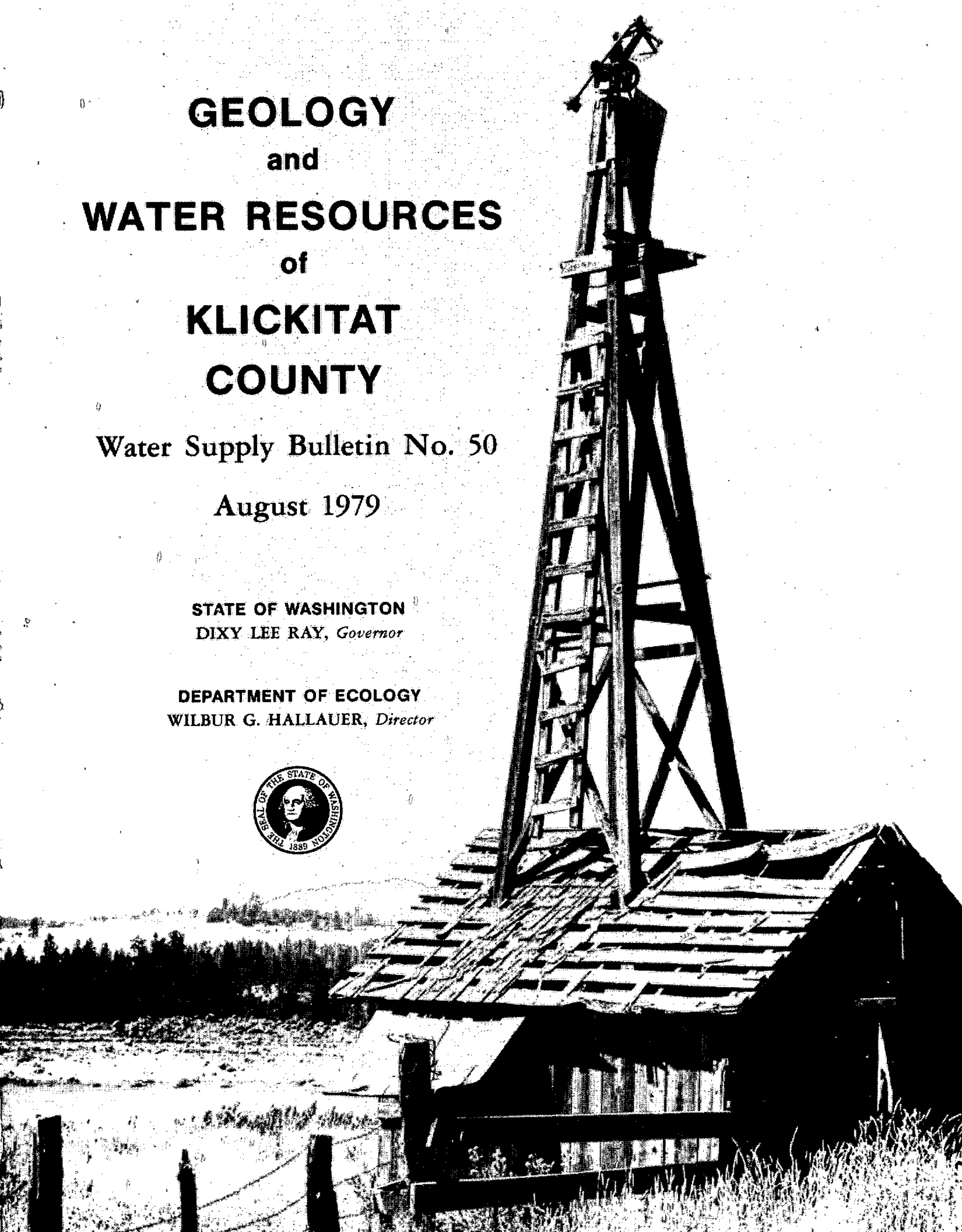

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When the well's dry, we know the worth of water.

<u>Poor Richard's Almanac</u>
(1746)

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ABSTRACT

The area investigated in this report encompasses about 2200 square miles including all of Klickitat County and that part of the Klickitat River basin north of the county. The study area lies just north of the Columbia River in south-central Washington and is bordered by the Cascade Mountains on the west. Elevations range from 72 feet in the southwest to 12,307 foot Mt. Adams in the northwest. Much of the area has rugged topography produced by deep canyons dissecting high plateau surfaces.

Climatic conditions within the county are normally cool and wet in the winter and warm and dry in the summer. Precipitation is greatest in the western edge of the county, and in the high elevations, reaching in excess of 100 inches per year on Mt. Adams. Precipitation decreases to less than 10 inches per year in the eastern part of the county. Unequal distribution of precipitation produces dense vegetation and conifer forests in the west which gradually change to sagebrush and sparse vegetation to the east. Substantial elevation differences that exist between plateau surfaces and valley bottoms also produce climatic and vegetational differences throughout the county.

Major geologic units are volcanics and interbedded sediments which range in age from Tertiary to Recent. The oldest rocks exposed, found in the extreme western part of the county, are tuffs and tuff breccias interbedded with lesser amounts of basaltic and andesitic lavas and may be equivalent to part of the Ohanapecosh Formation. Overlying these older volcanics are basalts of the Columbia River Basalt Group. These basalts are the principal unit exposed in the county and thicken from west to east.

In northern and western parts of the county, the Columbia River Basalt is overlain by both sediments and younger volcanics. The sediments include

quartizitic and andesitic conglomerates. The volcanics consist of basaltic and andesitic lavas of the Simcoe Mountains and young andesites from Mt. Adams and other eruptive centers in northwestern Klickitat County. On Camas Prairie, recent gravels of glacial and/or glaciofluvial origin overly the younger volcanics.

The geologic units are involved in a series of structures which decrease in magnitude and frequency from west to east. The structures are categorized in two groups: 1) primary east-west structures which are large amplitude folds running almost the entire length of the county, 2) secondary northwest-southeast trending structures which are a series of smaller folds superimposed on the primary structures. Deformation appears to have begun in the Pliocene and continued sporadically to Recent time.

Distribution of the county's surface-water resources is directly related to distribution of precipitation with the resource being abundant in the west and virtually absent in the east. Analysis of stream gaging data indicates streams in the west have uniform discharge throughout the year with minimum flows sustained by ice and snowmelt. In contrast, streams in the east are intermittent and exhibit the instantaneous effects associated with arid or semiarid conditions. Streams in the central part of the county represent a transition between the two extremes having high discharge during runoff months but very low minimum flows during dry months. Topographic and climatic conditions are favorable for flooding and major flooding has occurred as recently as 1974. Most of the damaging flooding has occurred in the Klickitat and Little Klickitat River basins.

Ground-water supplies within the county appear adequate with most ground-water obtained from wells in the basalts of the Columbia River Group. The extensive distribution of the basalt flows and the presence of highly

permeable interflow zones facilitate development of this ground-water resource. Well production varies from a few gpm to as much as 500 to 1000 gpm in irrigation wells. Some irrigation wells drilled in the extreme eastern part of the county yield 2000 to 3000 gpm.

In the northern and western part of the county, some domestic supplies are obtained from unconsolidated sediments and younger volcanics. Ground-water-supplies are barely adequate in areas such as the Goodnoe Hills where topographic and geologic factors limit available recharge.

The chemical quality of water within the study area is adequate for most uses. Surface-water quality is good with most of the examined parameters indicating a classification of AA according to the standards set by the Water Pollution Control Commission of Washington. Only total coliform exceeded the class AA limits for perennial streams in Klickitat County.

Ground water also appears to be of excellent quality. In most cases ground water tested has concentration of chemical constituents well below those allowed for public water supplies. In a few areas, iron content appears abnormally high and water drawn from sediments or basalts overlain by thick sediments, will often have high hardness. Isolated occurrences of wells and springs with very high chemical content exist in the Klickitat River valley.

Most registered claims for surface water are located in the western third of the county where surface supplies are most abundant. Many of the claims date back to the late 1800's and reflect the initial dependence upon surface-water supplies. Currently, 594 claims for a total of 568.55 cfs of surface water exist.

Claims for ground water predominate in the central and eastern part of the county and most of the demand for ground water has occurred since 1950.

Development of deep well irrigation in the Goldendale-Centerville area and extreme eastern Klickitat County has led to substantial increase in ground-water use. Review of water rights indicate 401 claims for a total of 157,913.5 gallons per minute are presently recorded. A notable increase in claims for both surface and ground water is present from 1965 to 1975 and may be in part because of the Water Right Claim Registration Act. Currently, surface-water supplies are near fully appropriated and ground-water supplies appear to keep pace with demand. The ability of ground-water supplies to support further demand is unknown. Areas within the county in which potential problems could develop include the Bickleton area, Dead Canyon and Alder Creek basins, and the Goldendale-Centerville area.

INTRODUCTION

This study of Klickitat County and the upper Klickitat drainage area was done at the request of the Washington State Department of Ecology by the Geohydrology Section, College of Engineering, Washington State University. The study is part of a continuing effort by the Department of Ecology to inventory the state's water resources on a regional basis. Such an inventory will facilitate the understanding and subsequent management of the state's valuable water resources.

Purpose and Scope

In the past 30 years, development of Washington's water resources has rapidly intensified. Increased demand for domestic, municipal, industrial, and agricultural purposes and an improved water production technology have resulted in a dramatic increase in the use of both surface- and ground-water supplies. Concern over long-range effects of this increased use has led to the development of a water resource management program. The ultimate goal of such a program is to assure adequate supplies of the resource in the future. Development of a realistic management program for any area depends upon a thorough understanding of the area's water resources and the factors which affect their distribution and occurrence. This report is designed to present basic information necessary to such an understanding for Klickitat County and the upper Klickitat River basin.

The study combines existing data on meterology, geology, surface and ground water, and water quality, with additional information obtained through field work. Work commenced on the study in January 1975 with most data collection being completed by March 1977. Field work was accomplished during 1975 and 1976. The study is reconnaissance in nature and presents basic information for water resource research, management, and use.

Location and Extent

The area of study is located in the southernmost part of Washington State (Figure 1) and includes all of Klickitat County and the part of the

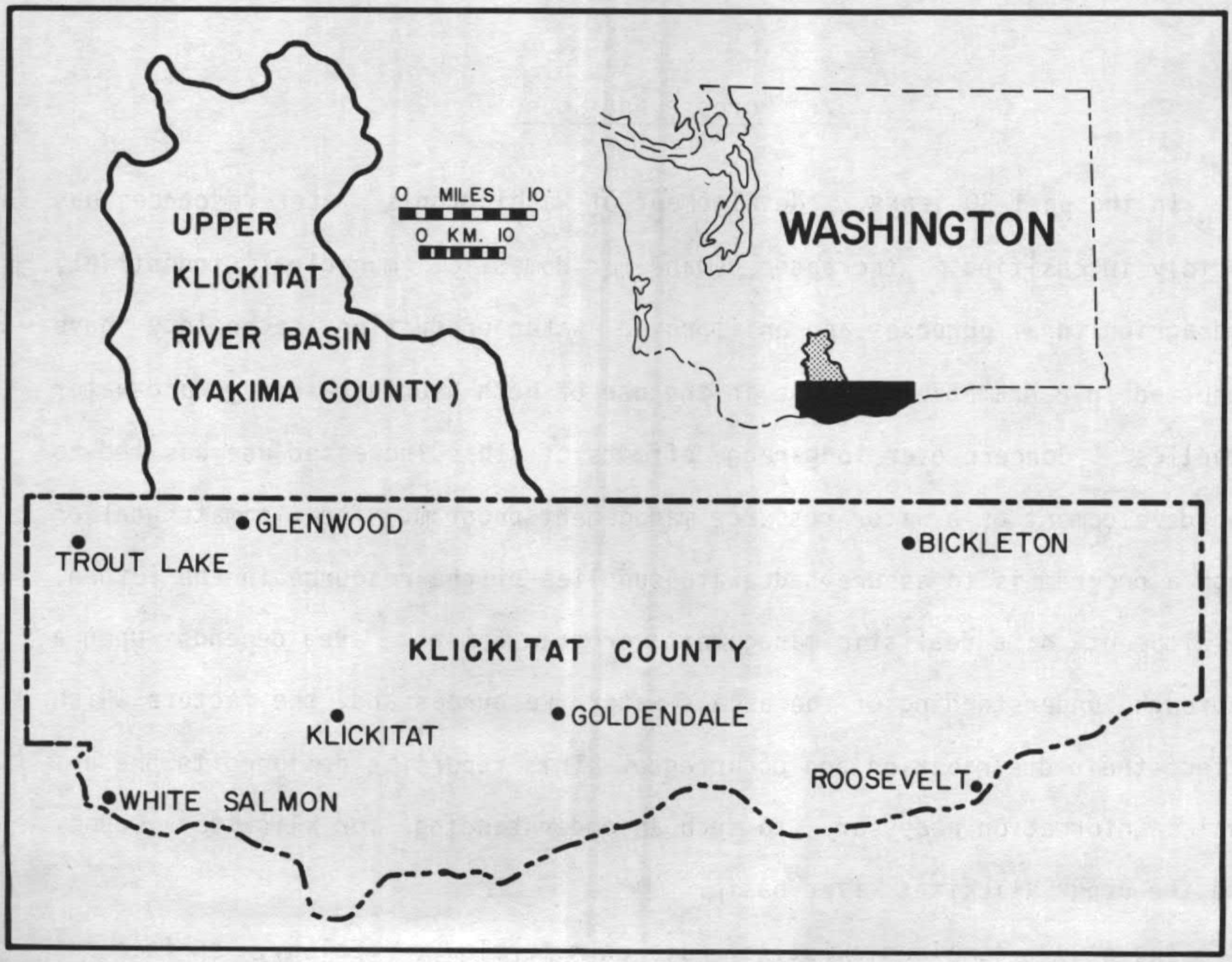

FIGURE 1. Location of investigated area, Klickitat County and the upper Klickitat River basin, Washington.

Klickitat River basin extending north into western Yakima County. Klickitat County has an area of about 1800 square miles and includes parts of Townships 2 through 6 North of the Willamette Base Line and Ranges 10 through 23 East of the Willamette Meridian. The upper Klickitat basin lies north of the county and includes an area in excess of 400 square miles in parts of Townships 7 through 12 North and Ranges 11 through 16 East.

Previous Work

Previous studies in the Klickitat County area have dealt primarily with geology in the immediate area of the Columbia River gorge. Earliest work by Russell (1892) included parts of Klickitat County in a reconnaissance of central Washington. Later, Waring (1913) studied eastern Klickitat County in a general geologic and water resource investigation of south-central Washington.

Williams (1916) initially described much of the Columbia River gorge structure with subsequent work done by Hodge (1931), Piper (1932), and Newcomb (1967, 1969). Bretz (1917) investigated sedimentary deposits in the gorge. Work on the origin and nature of these deposits was continued by Buwalda and Moore (1930), Warren (1941a, 1941b), Waters (1955), and Newcomb (1966, 1969).

Definition of geology and geologic structures elsewhere in the county includes work by Sheppard (1960), who studied in the Simcoe Mountains and later (1967) produced a map of the area. Sheppard (1964) also produced a geologic map of the Husum Quadrangle in western Klickitat County. Other geologic investigation of the western part of the county consists mainly of reconnaissance mapping by Hammond (1973).

Research by Laval (1956) and Schmincke (1964) and later work by Newcomb (1971) provide information on stratigraphy and structure of parts of eastern Klickitat County. In addition, geologic reconnaissance done by Shannon and Wilson, Inc. (1973, 1974) includes much of the eastern half of the county. General geologic information for the entire study area is presented in maps by Huntting and others (1961) and by Newcomb (1970).

Analyses of water resources of the Klickitat County area are sparse. Discussion of the area's surface-water resources are virtually nonexistent, although information on surface-water resources of the upper Klickitat River basin is presented by Cline (1976). Information on floods, primarily in the Klickitat River basin, was developed by Longfield (1974) and Cline (1976).

Early reconnaissance work by Waring (1913) and Piper (1932) provide some information on ground-water resources in eastern and southern Klickitat County. Studies by Newcomb (1969) and Luzier (1969) provide a more recent ground-water resource evaluation of the Columbia River gorge and the Goldendale-Centerville areas. Work by Newcomb (1971) and Crosby and others (1972) provide additional information on ground-water resources in eastern Klickitat County. Ground-water resources in the Glenwood area of western Klickitat County were examined by Cline in 1976.

Acknowledgements

This study was a team effort, and many people deserve recognition for their contributions.

Lynne Covell, Krystyna Kowalik, Mike Robinette, Steven Strait, Kevin Sylvester, and Tom Weber assisted in data collection assembly. Carol Bohringer, Jaydee McCrackin, Cathy Naugle, Rick Ward, and Diane Weber were instrumental in manuscript preparation. James W. Crosby, III, critically edited the manuscript.

The Washington State Department of Ecology and the U. S. Geological Survey provided much of the data on ground- and surface-water resources and water use. Special thanks are due to Peder Grimstad of the Department of Ecology for his patience and to Denzel Cline and Rod Williams of the U. S. Geological Survey for their assistance in providing much valuable data.

Conversation and field observation with Paul Hammond, Portland State University, Robert Bentley, Central Washington University, and Don Swanson, U. S. Geological Survey, were helpful in understanding geological problems.

Ken O'Leary of O'Leary Drilling and Dick Murray of Murray Well Drilling provided valuable information on subsurface conditions and ground-water occurrence within the county. In addition, assistance from personnel of the Soil Conservation Service, Washington State Department of Natural Resources, Klickitat County Regional Planning Council, Klickitat County Public Utility District, Portland General Electric Company, Pacific Power and Light Company, Shannon and Wilson, Inc., and Martin-Marietta Corporation is gratefully acknowledged.

Finally, special thanks are extended to the good people of Klickitat County who graciously allowed access to land and wells and provided much valuable information.

CHARACTERISTICS OF THE REGION

The study area is bordered on the west by the Cascade Mountains and occupies a transition zone between the mountains and the Columbia Plateau to the east. Most of the county occupies a southward-sloping surface which extends from the Horse Heaven Hills, near the county's northern border, to the Columbia Hills in the south.

The Columbia River lies along the southern margin of the county and, because of geologic structure and erosion, it occupies a canyon much lower in elevation than other areas of the county. The elevation of the Columbia River in this reach varies from 72 feet above MSL at the western county line to 265 feet. As a result of these elevation differences, streams draining interior parts of the county have carved deep north-south canyons. These deeply incised streams have produced substantial topographic relief throughout the county and have created a series of high, plateau-like surfaces separated by deep, narrow canyons.

The upper Klickitat River basin is an area of extremely rugged topography. Elevations in much of the area are higher than 3000 feet, with the highest point being Mt. Adams (12,307 ft). The relatively low base level of the Klickitat River has resulted in deep cutting by tributaries in the upper basin and has produced the very steep, rugged topography characteristic of the area.

Climate

Klickitat County occupies a zone of climatic transition between the relatively moist conditions prevalent west of the Cascades and the semiarid conditions to the east. Winters are normally wet, with the western part receiving a substantially higher rainfall than the eastern part. During summer months, the county is normally warm and dry.

The county's weather is primarily controlled by the high-pressure air mass normally present in the northeast Pacific Ocean during the summer and the low-pressure air mass that normally occupies the Gulf of Alaska in winter. To a lesser extent, two geological factors, the Cascade Mountains and variation of elevation within the county also affect the weather.

During summer months, the high-pressure air mass usually dominates weather, sending air into the area from the west. Since the ocean is nearly constant in temperature throughout the year, air flowing in from the ocean during the summer months is cooler than the land. The air warms as it moves inland, which results in warm, dry summers. East of the Cascades the lack of the ocean's direct moderating effect results in even warmer and drier conditions that are present to the west.

In winter the decrease in solar radiation causes a weakening of the high-pressure system, and it gradually migrates southward. Concomitant with the weakening of this system, the low-pressure system in the Gulf of Alaska expands, exerting a greater influence and causing the systems to drift eastward over the continent. Counterclockwise movement of the air around these low-pressure cells normally produces a flow of air from the west and southwest. Relative to the land temperatures, the air mass is warm and moist. When this air reaches the land, it cools and condenses, producing abundant precipitation during the period from October to March. As the moist air is forced upward by the Cascades, additional precipitation occurs either as rain or snow. In the lee of the Cascades, the air mass moves to lower elevations, is warmed, and the process is reversed. Thus, a dramatic difference in precipitation is evident between the east and west sides of the Cascade Mountains. This change in precipitation resulting from the presence of the mountain is referred to as an orographic or rain-shadow effect.

Basic Data

Figure 2 presents a general summary of meterological data-collection stations within Klickitat County. A total of 15 recording stations have been established in the county, but only seven are presently in operation. Both daily temperature and precipitation information are obtained at all stations except Glenwood, where only precipitation is recorded.

Most of the long-term stations have been relocated several times. Mass density survey analyses were made of the stations at Goldendale, Bickleton, and Dallesport to see if these location changes substantially affected the long-term record. Although some variation was noted, it did not appear to correlate with changes in location. For general comparison purposes, these location changes should have little effect.

Three of the seven stations were selected for analysis and comparison of general climate areas within the county. The three stations selected for comparison are located at Mt. Adams Ranger Station, at Goldendale, and at Bickleton. The station at Mt. Adams Ranger Station records climatic conditions indicative of the western part of the county, while the stations at Goldendale and Bickleton are indicative of the central and eastern parts of the county, respectively.

Precipitation

Distribution of annual precipitation within the study area is shown in Figure 3. As expected, precipitation is highest in the northern and western areas and decreases markedly to the east and south. The decreasing

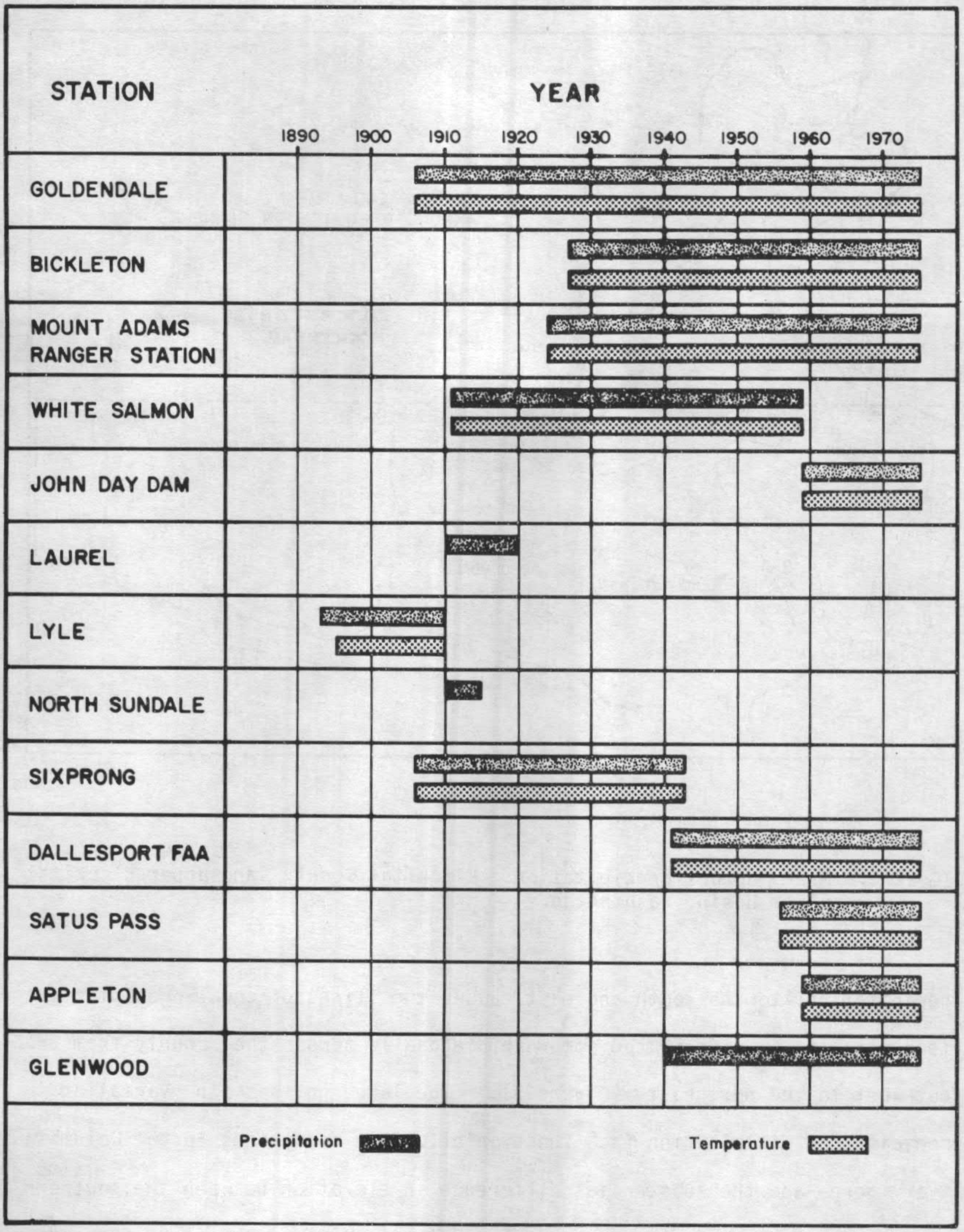

FIGURE 2. Barchart showing period of data collection for selected weather stations, Klickitat County, Washington.

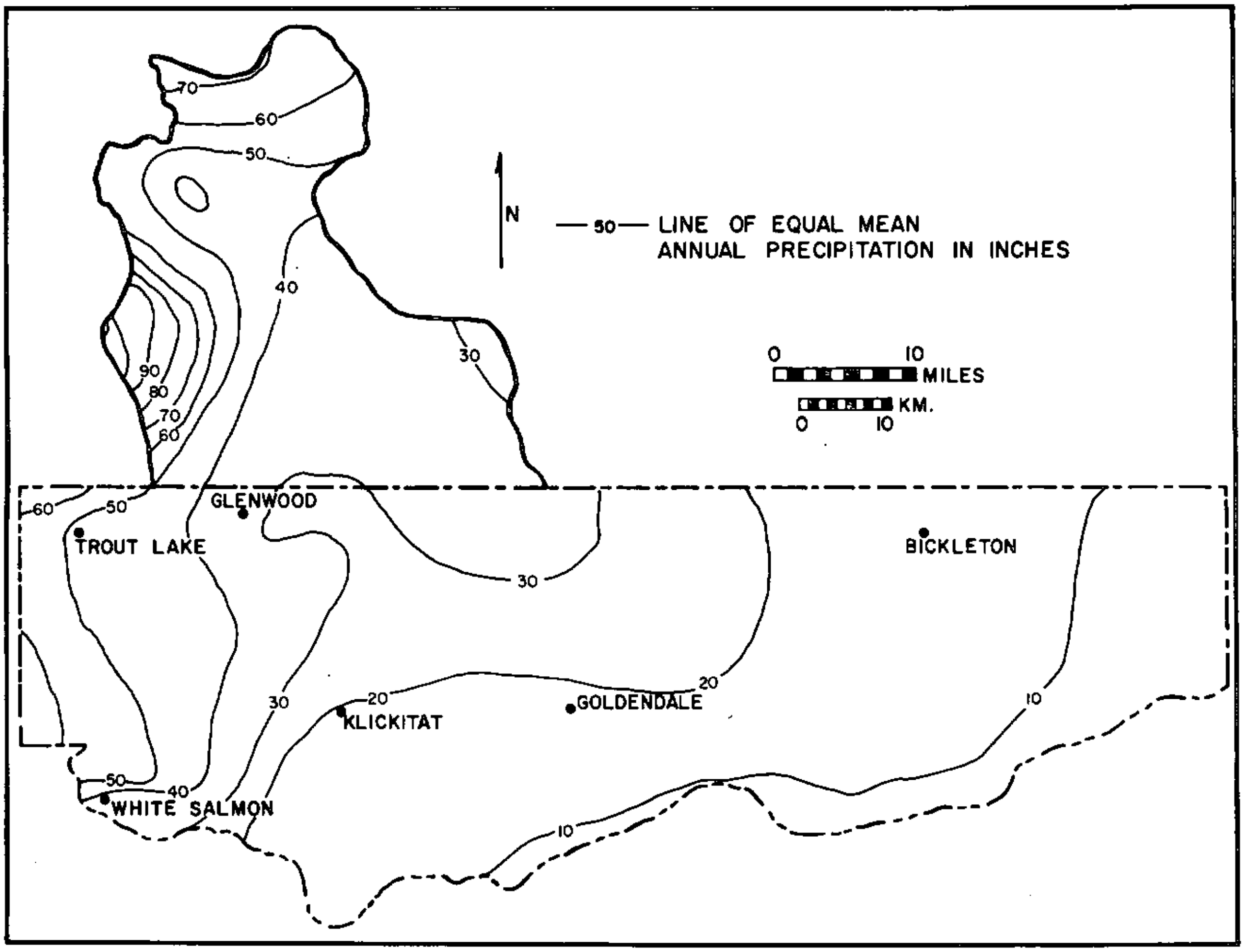

FIGURE 3. Mean annual precipitation, Klickitat County and upper Klickitat River basin, Washington.

precipitation to the south and east causes the lines of equal precipitation (isohyets) to be distributed somewhat diagonally across the county from the southwest to the northeast (Figure 3). The large north-south variation in precipitation distribution is a function of unique conditions in the Columbia River gorge and the substantial difference in elevation between the southern and northern parts of the county. The Columbia River gorge along the county's southern margin is normally warm and dry because of its low elevation and location immediately east of the water gap cut through the Cascade Mountains. The restricted area available for air flow through the gap causes compression of air on the west side, which tends to increase condensation. Once through the gap, the air is able to expand, increasing its ability to absorb moisture. The combination of warm temperature at the low elevation and the expansion of the air mass immediately east of the water gap produces extremely warm and dry conditions along the county's southern margin.

To the north, the relatively high elevation of the Horse Heaven Hills results in substantially cooler temperatures than in the gorge. Like the Cascades to the west, cooler temperatures produce greater condensation and cause annual precipitation along the Horse Heaven Hills to be greater than in areas of lower elevation immediately to the south. Because the Horse Heaven Hills extend well into eastern Klickitat County, so does this orographic effect. Thus, some of the isohyets presented in Figure 3 assume a strong northeasterly trend, extending from the Columbia River gorge in the western half of the county to the Horse Heaven Hills in the eastern half.

Comparison of monthly precipitation data for the three selected stations (Figure 4) illustrates the decrease in precipitation occurring from west to east within Klickitat County. Most of the county's precipitation occurs during the winter months with maximums at each station occurring in either December or January. Monthly minimums occur in July and August. Examination of Figure 4 reveals that, although annual precipitation varies greatly among the three stations, mean monthly precipitation for the month of July at each station is nearly equal. This similarity attests to the general distribution of the limited amount of precipitation received in the summer months within the county.

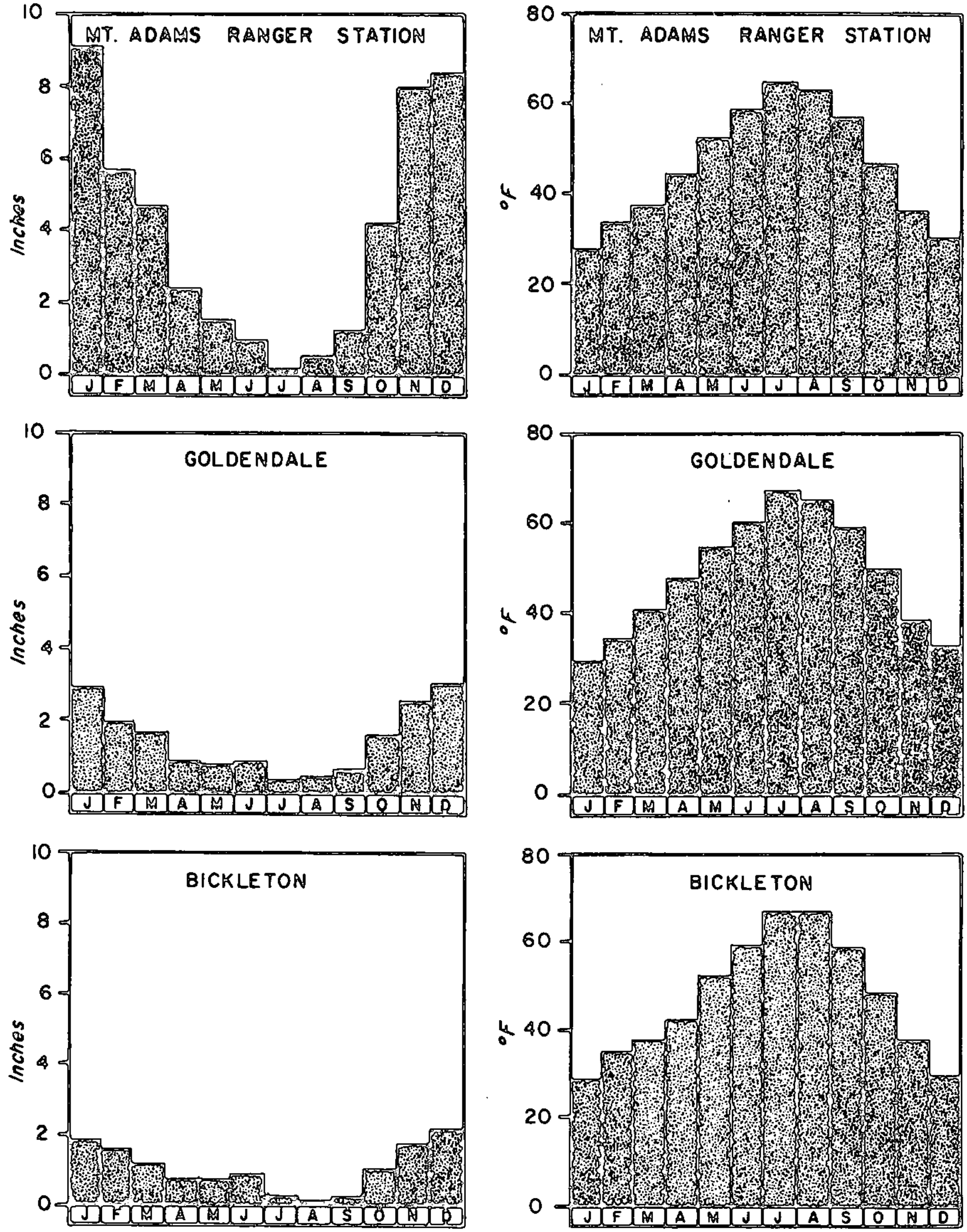

FIGURE 4. Monthly mean precipitation and temperature for stations at Mt. Adams Ranger Station, Goldendale and Bickleton, Washington.

Examination of ten-year moving averages indicates that the long-term correlation of the three stations is not as direct as might be expected. Although the same general trends can be seen in Figure 5, a close correlation does not exist. In the last five years, for example, the moving averages in the Bickleton area appear to have increased to an all-time high. A similar, though less intense, rise is noted at Mt. Adams Ranger Station. The record

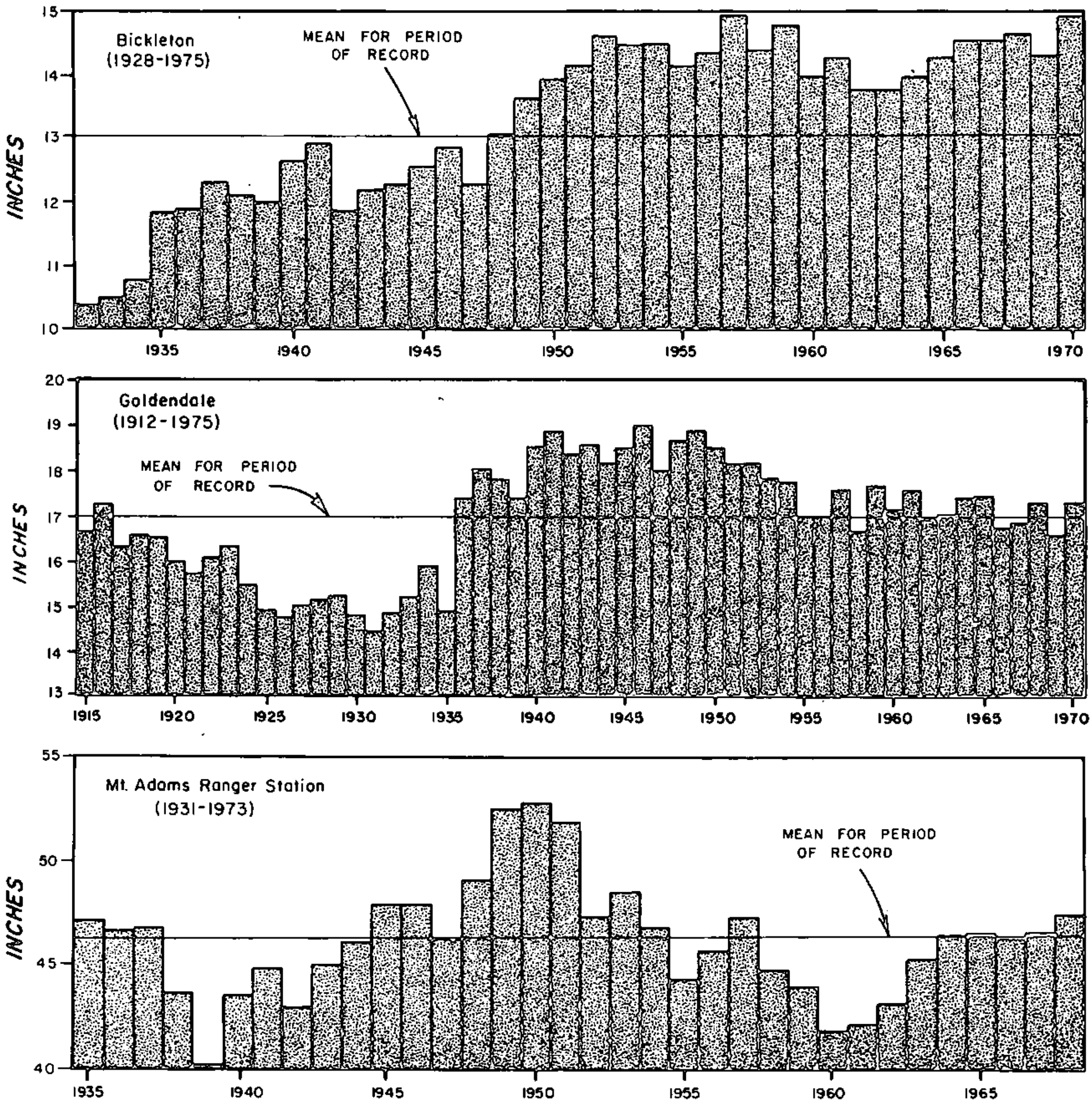

FIGURE 5. Ten-year moving average of precipitation at selected stations, Klickitat County, Washington.

for Goldendale, however, indicates little if any overall increase in the last five years. Reasons for this variation are not apparent but may be because storm movement across the county is often in a northeasterly direction rather than due east.

Moving averages reflect the periodic precipitation changes for the county. Figure 5 reveals low precipitation in the 1920's and 1930's followed by high precipitation in the 1940's. Precipitation throughout the county for the last 10 to 15 years has been about equal to the mean for the period of record, although in the Bickleton area it has been slightly higher than the mean.

Temperature

Annual temperature variation within Klickitat County reflects the changing influence of the dominant air masses and the moderating influence of the Pacific Ocean. Winter temperatures are moderate, reflecting the strong marine influence; average temperatures in January (the coldest month) are only slightly below freezing. Similarly, summer temperatures are moderate, with averages among the three stations for the month of July ranging from 65 to 70°F. The summer averages are misleading, in a sense, because the county normally experiences substantial cooling after sunset which is reflected in the averages. Thus, daytime maximum temperatures during the summer can be considerably warmer than the average.

Comparison of the three selected stations (Figure 4) reveals strikingly similar average monthly temperatures. The close similarity among the three widely separated stations at Mt. Adams Ranger Station, Goldendale, and Bickleton indicates the importance of elevation in controlling temperature. Although there is a general trend toward slightly warmer conditions from west to east within the county, this does not appear to be reflected in monthly averages, probably because the station at Bickleton is almost 1400 feet higher than that at Goldendale and 1100 feet higher than Mt. Adams Ranger Station. The effect of elevation upon temperature is also reflected in comparisons of temperature data from stations within the Columbia River gorge with those to the north. Recording stations at Dallesport and John Day Dam indicate January and July averages to be from 5 to 10°F warmer than the station at Goldendale.

Figure 6 presents the mean annual temperature for the station at Goldendale for the period of record. Examination of the figure indicates that variation in the mean temperature is less than 10°F with periods of lower-than-average temperature occurring in the early 1920's and 1930's and in the late 1940's. Higher-than-average temperatures occurred in the 1940's and in the mid-1960's.

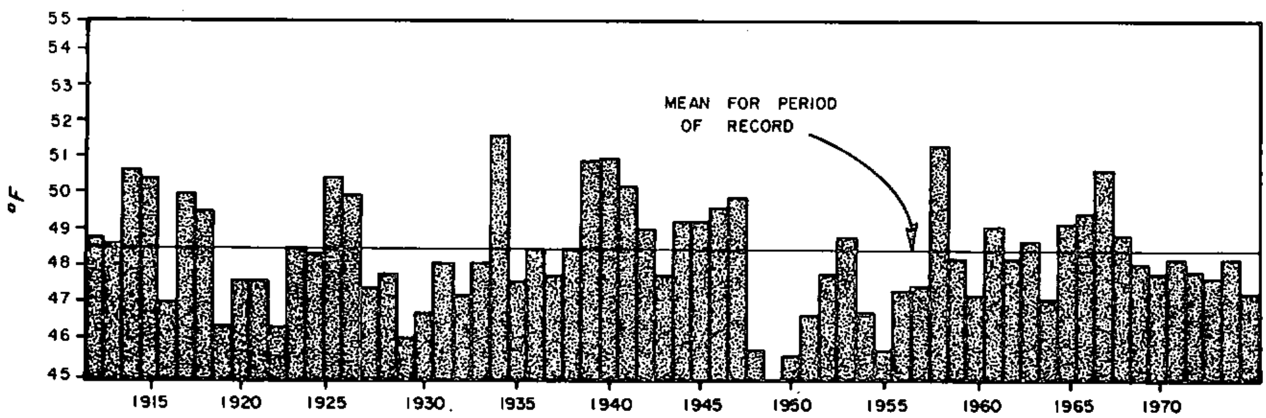

FIGURE 6. Mean annual temperature (1912-1975), Goldendale, Washington.

Water Budget

The water budget is the relationship between contribution and loss of water in a selected area. The relationship, normally presented in a water budget diagram, involves the amount of water available to an area from precipitation minus that which is lost by evaporation and transpiration from plants (evapotranspiration). The net result is an indication of the amount of water available for runoff and soil moisture recharge in the area.

Calculation of the water budget depends upon an accurate determination of water lost to evapotranspiration. A method developed by Thornthwaite and Mather (1957) is used for determination of evapotranspiration. The method is based upon the relationship between latitude and temperature, because evapotranspiration is directly related to solar insolation. As a consequence of this relationship, highest evapotranspiration normally occurs in summer.

The Thornthwaite method assumes a root zone holding capacity of 11.8 inches, which is probably excessive for most of Klickitat County. For this reason, water budget calculations presented here are most useful as an indicator of general relationships rather than as sources for reliable quantitative data.

Figures 7 through 13 present water budget diagrams for several stations throughout Klickitat County. On the diagrams, mean daily precipitation, mean daily evapotranspiration, and actual evapotranspiration are plotted. Within the county, precipitation and evapotranspiration vary inversely. For this area, evapotranspiration is lowest during high-precipitation months and highest during low-precipitation months. When precipitation is exceeded by evapotranspiration, demand for soil moisture exceeds the supply and a water deficit is created. This deficit is the difference between potential and actual evapotranspiration. The difference between actual evapotranspiration and

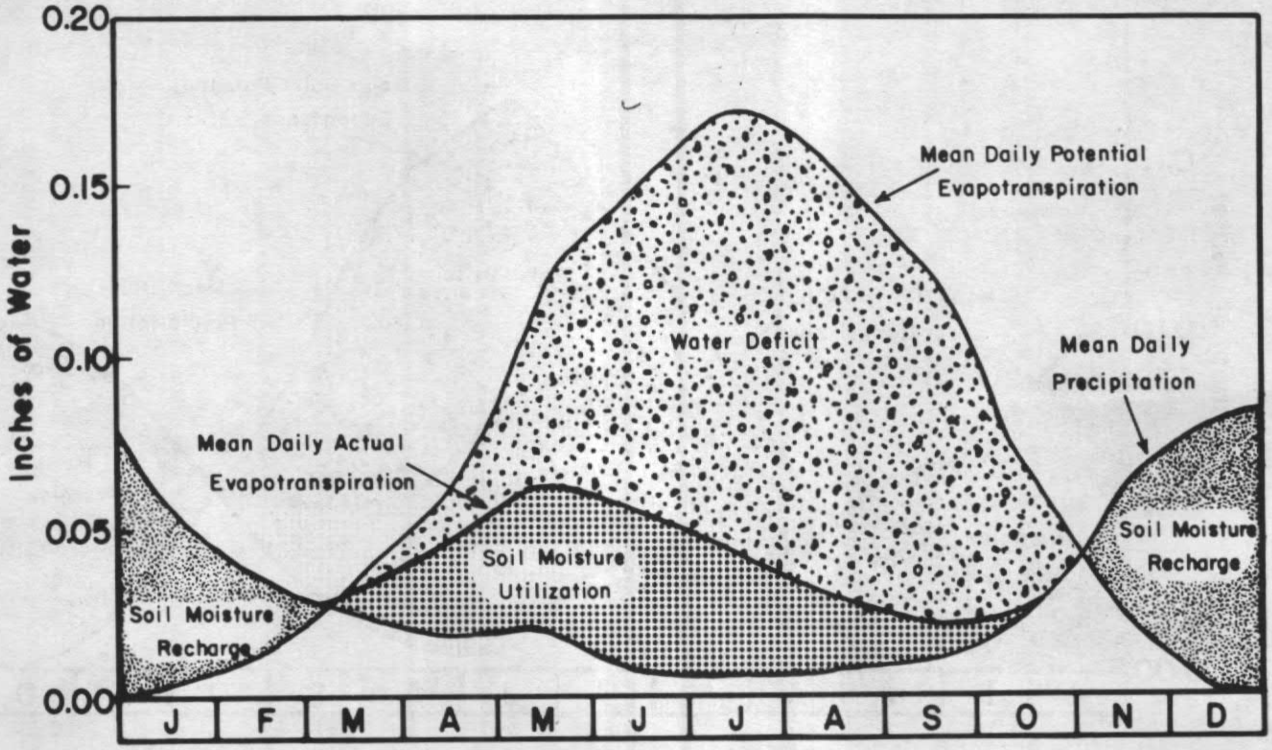

FIGURE 7. Mean annual water budget, John Day Dam, Klickitat County, Washington.

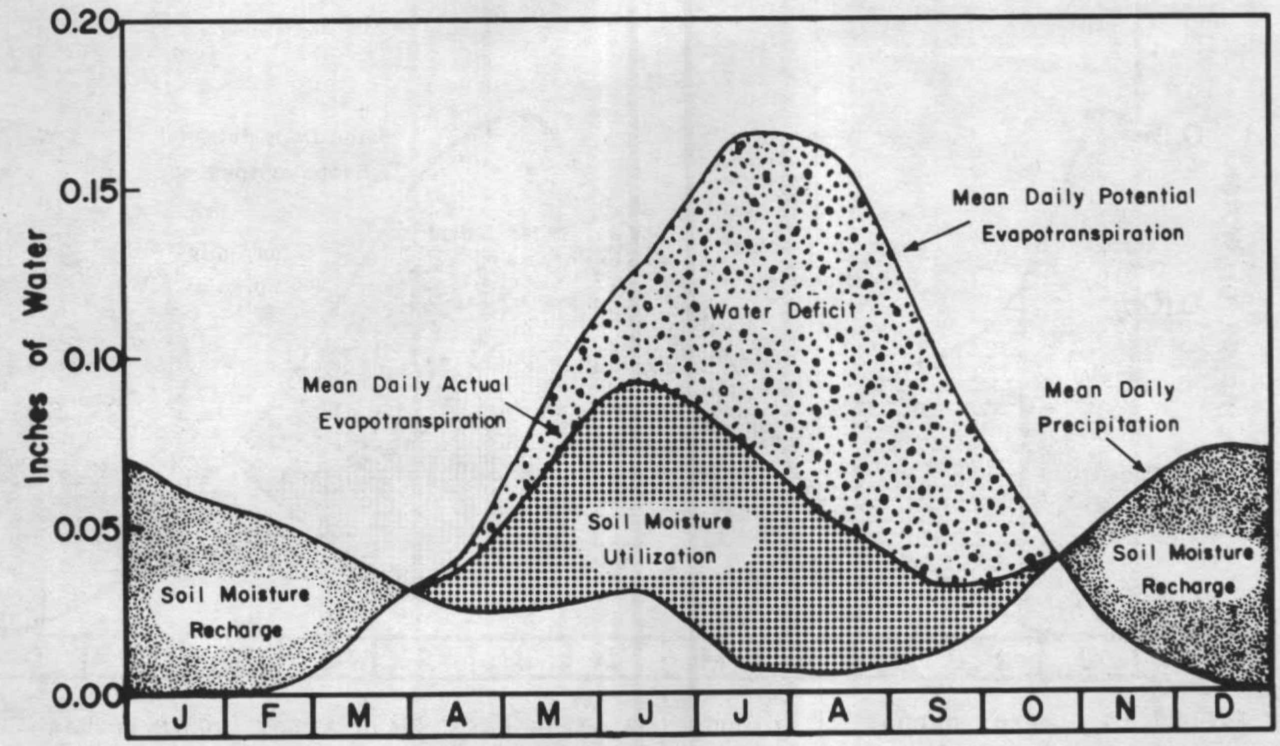

FIGURE 8. Mean annual water budget, Bickleton, Washington.

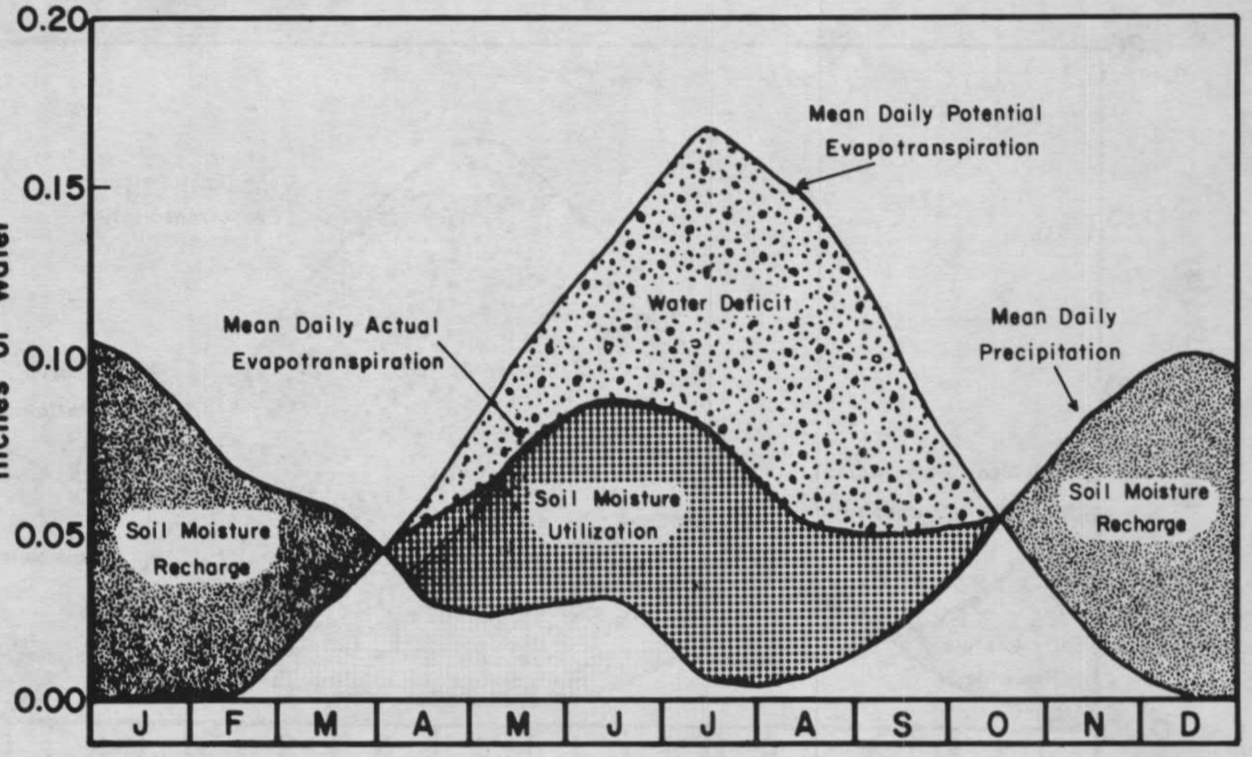

FIGURE 9. Mean annual water budget, Goldendale, Washington.

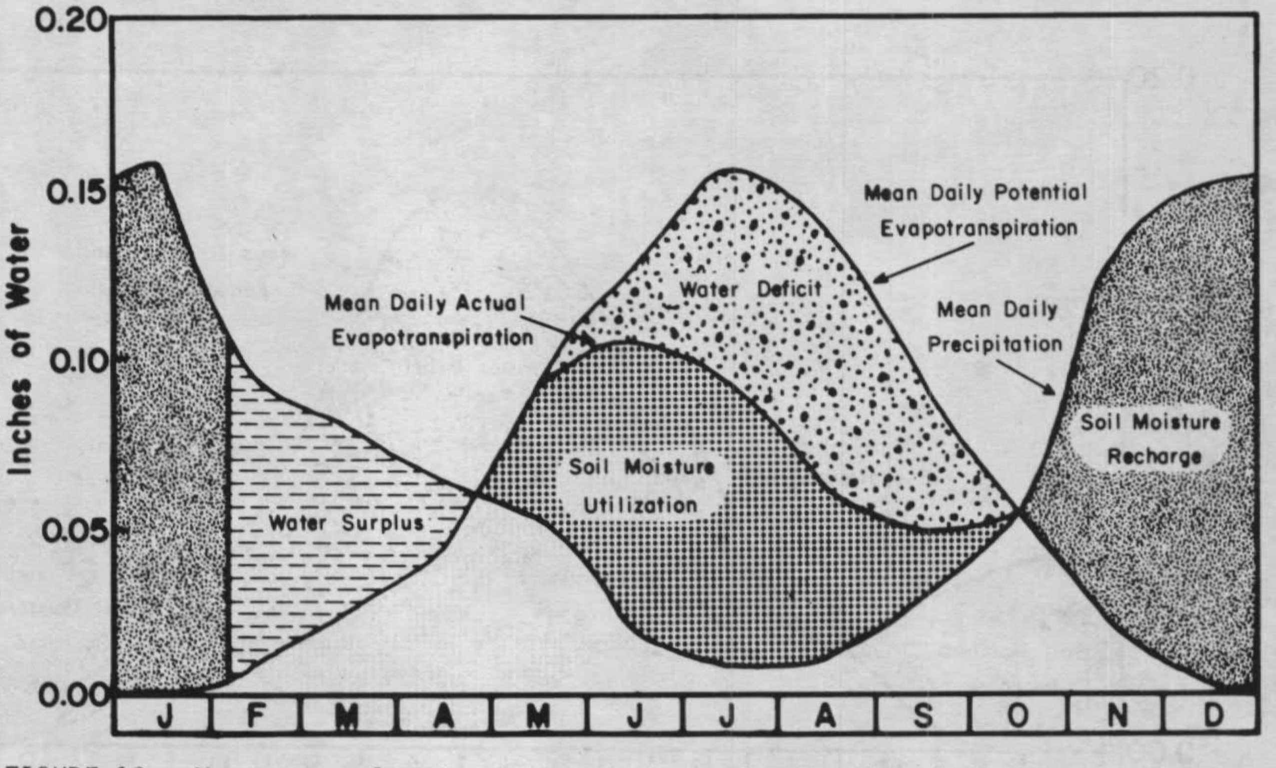

FIGURE 10. Mean annual water budget, Satus Pass, Klickitat County, Washington.

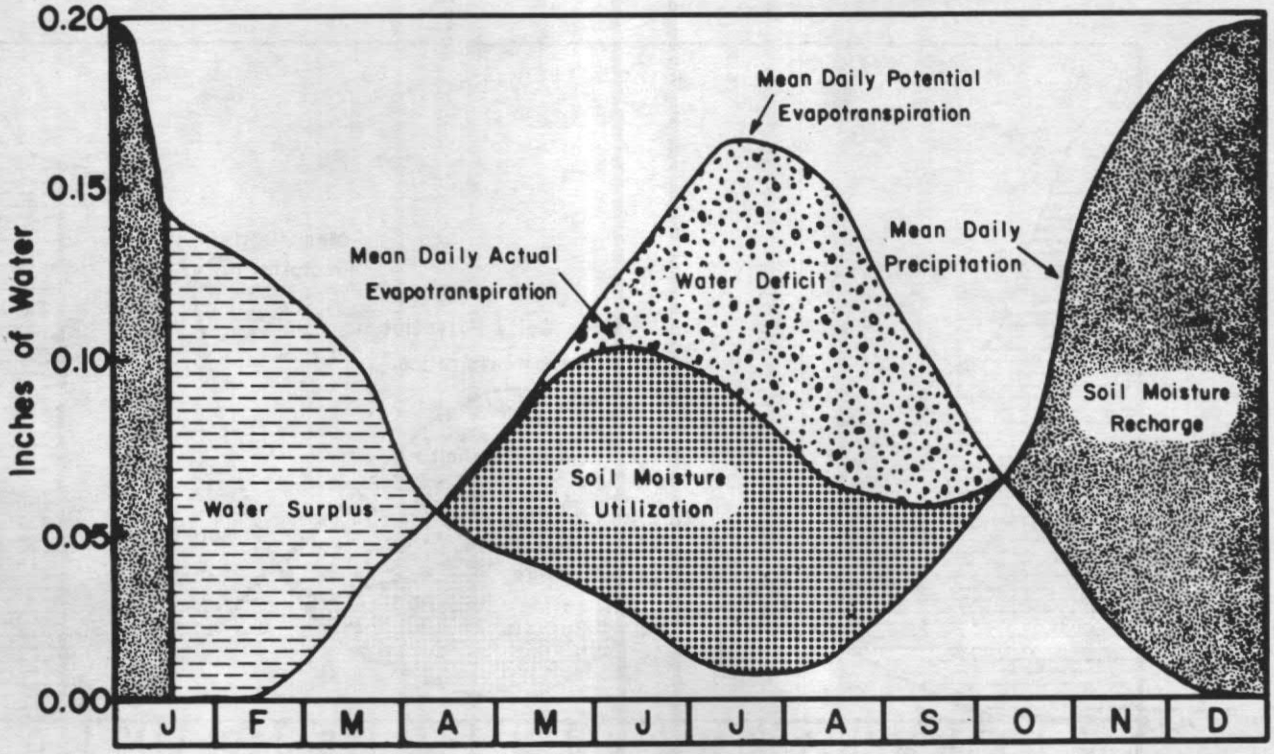

FIGURE 11. Mean annual water budget, White Salmon, Washington.

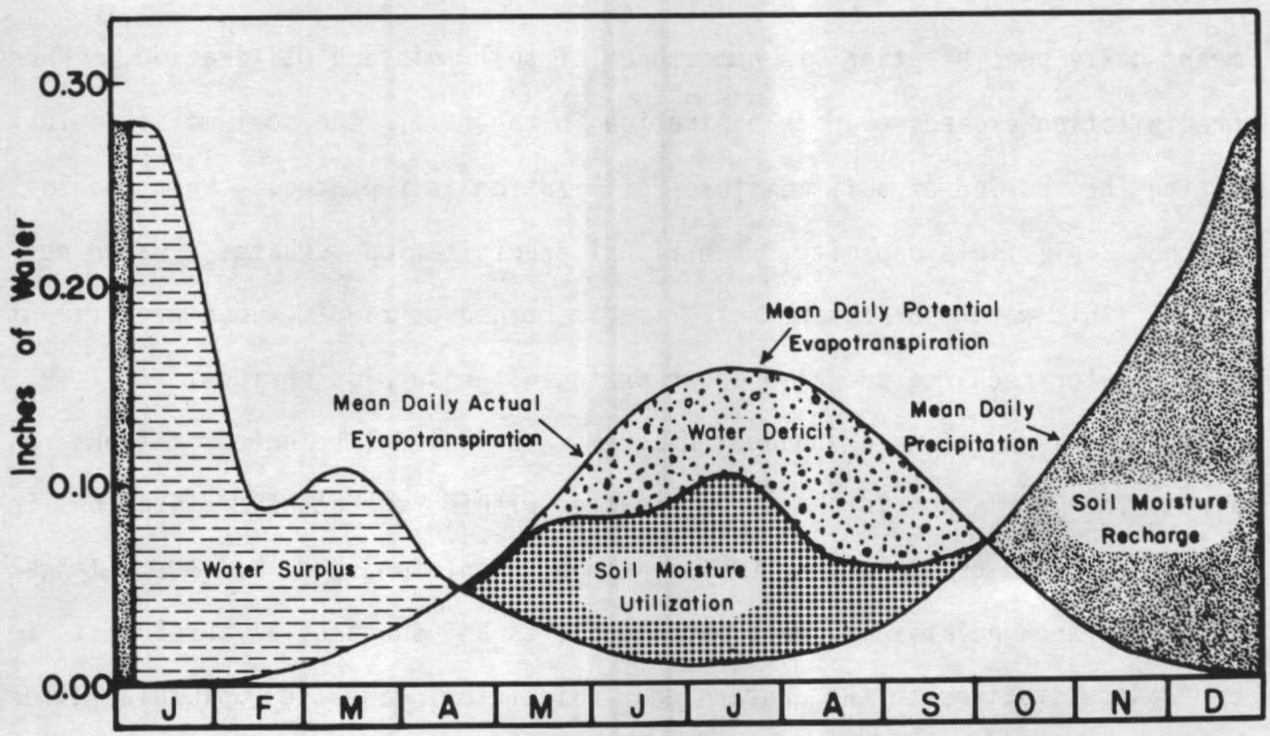

FIGURE 12. Mean annual water budget, Appleton, Washington.

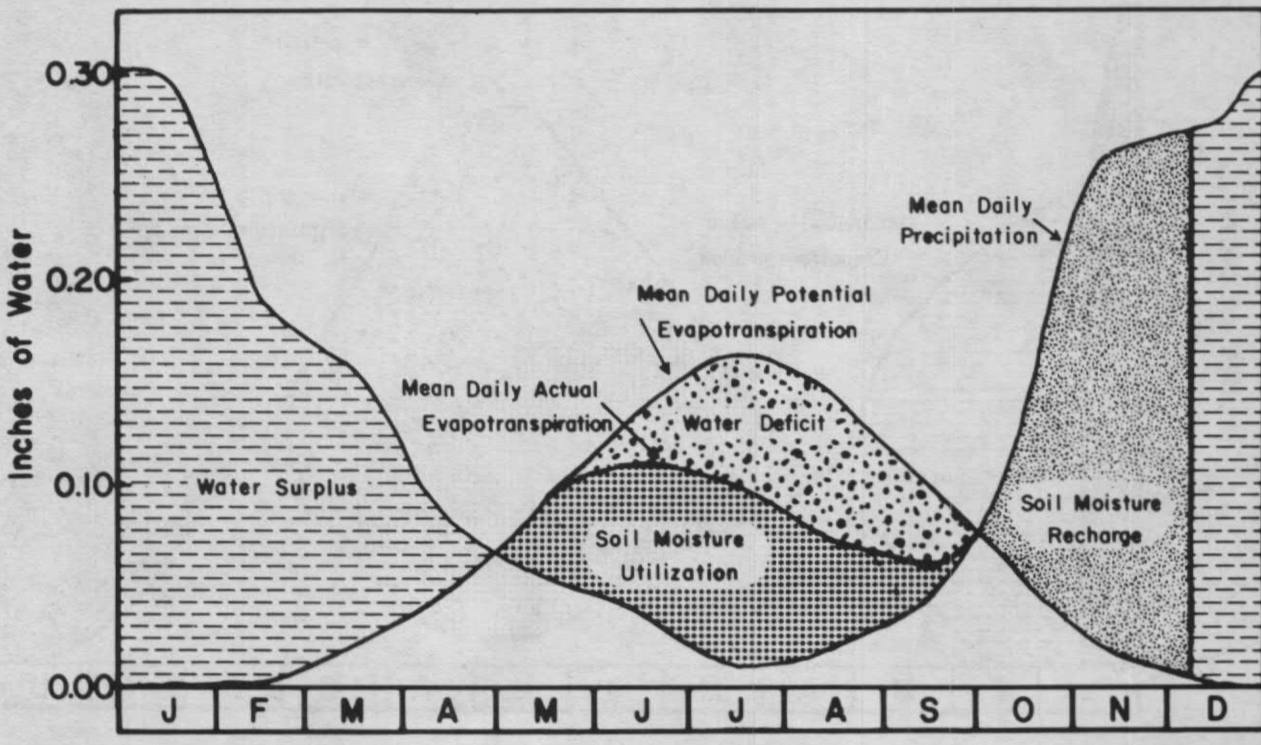

FIGURE 13. Mean annual water budget, Mt. Adams Ranger Station, Klickitat County, Washington.

mean daily precipitation is a measure of soil moisture utilization. When precipitation exceeds evapotranspiration in the fall, the soil moisture lost during the period of soil moisture utilization is replaced. When the soil reaches full field capacity, additional precipitation creates a water surplus. This water surplus normally is discharged as runoff, but significant ground-water recharge can also occur during water surplus periods.

Comparison of water budget diagrams for several selected stations reflects the variation in the precipitation within the county. Stations in the western end of the county (White Salmon, Appleton, and Mt. Adams Ranger Station) show relatively small water deficits and substantial surpluses. In contrast, stations in the eastern end (Bickleton) and the Columbia River gorge (John Day Dam) have large water deficits and no water surpluses. Comparison of the Goldendale and Satus Pass diagrams illustrate the orographic effect. Goldendale has a moderately large water deficit and no surplus, while the station at Satus Pass has a much smaller deficit and a small water surplus in the spring.

Vegetation

Klickitat County exhibits remarkable contrast from west to east because of its long east-west dimension and its position relative to the Cascades. In response to the differences in precipitation, vegetation changes markedly from west to east. In isolated areas in the extreme northwest part of the county, abundant precipitation produces vegetation very similar to that found on the west side of the Cascade Mountains. Thick conifer forests containing Douglas-fir with vine maple, rhododendron and huckleberry occur. To the east, the forest contains more pine and less abundant undergrowth. Conifer forests extend over much of the western third of the county with oak trees locally in abundance. The forests become thinner east of the Klickitat River canyon; however, dense forests are present at higher elevations along the Simcoe Mountains and Horse Heaven Hills, well into the eastern half of the county. East of the Klickitat River to the eastern edge of the county, the decrease in precipitation causes a transition from the combination of dry forest and grassland of the Goldendale area to the sage brush and cheat grass characteristic of the more arid parts of eastern Washington.

Areal Geography

The overall size of Klickitat County as well as its position relative to major geographical features results in extensive geographical diversity throughout the area. This geographical diversity necessitates division of the county into several areas of similar geography for discussion purposes.

Location of the county's principal communities and drainages are presented in Plates I, II, and III.

Eastern Klickitat County

Most of the county east of Rock Creek is quite similar. With the exception of a part of the Horse Heaven Hills to the north, the area receives little rainfall. When precipitation does occur, lack of vegetation and high relief produces relatively high runoff. As a result, the area has numerous deep canyons but virtually no perennial streams.

The eastern part of Klickitat County, an area of about 600 square miles, has a limited population. Only one community, Bickleton, exists in this area; it has a population of less than 100. Most of the inhabitants are engaged in agriculture, principally dryland farming and cattle production. Farming is practical only on the relatively flat, undissected areas, while the canyons are used principally for grazing. There has been an expansion in irrigated agriculture in the eastern area with recent development of adequate ground-water supply. Crops here are mainly wheat, potatoes, and sugar beets.

Goldendale-Centerville Area

The Goldendale-Centerville area in central Klickitat County is located between the Rock Creek and Klickitat River canyons. This area contains about 700 square miles, divided between conifer forests in the higher northern part and agricultural land in the lower southern part. The northern part is drained by the Little Klickitat River which flows year-round, while the south is drained by intermittent Swale Creek.

The economy of the Goldendale-Centerville area is based principally on agriculture and timber products. The northern part of the area provides substantial forest products, with logging and related milling employing a large number of the area residents. In the southern part of the area, relatively level undissected land and adequate water supplies have resulted in extensive agricultural development. Wheat and alfalfa are the principal crops with irrigation facilitating good production; however, because of the area's elevation the growing season is somewhat limited.

As a result of the combination of forest products and agricultural industries, the Goldendale-Centerville area contains the highest population of the county. Goldendale, the county seat of Klickitat County, has a population of 3275, and population density of the surrounding agricultural areas is higher than most other areas in the county.

Lower Klickitat River Valley

The lower Klickitat River valley extends from the confluence of the Little Klickitat River to the mouth of the Klickitat River near Lyle. The valley is steep-walled and narrow with the valley floor elevation 1000 to 1500 feet lower than the surrounding plateau surfaces. This elevation difference contributes to a milder climate than on the plateau areas.

Although the valley bottom is narrow, there is considerable habitation along the banks of the river. The small community of Wahkaicus is located at the confluence of Swale Creek and the Klickitat River, and about three miles south is the town of Klickitat. In addition to these communities, numerous homesites are located throughout most of the lower valley.

Economic support for the area is principally from the forest products industry, which employs many lower-valley residents. Klickitat is a "company town" of the St. Regis Company and a lumber mill is located here. A small amount of farming and stock grazing is also practiced in the lower valley.

Camas Prairie-Upper Klickitat Basin

The Camas Prairie-upper Klickitat basin area includes the Klickitat River drainage basin above the confluence of Outlet Creek. Although Camas Prairie and the upper Klickitat River basin are part of the same drainage basin, they exhibit distinct geographical differences.

Camas Prairie is a triangular-shaped area of about 50 square miles including most of the Outlet Creek drainage basin. The prairie is nearly flat, with elevation generally varying less than 100 feet, but is surrounded by much more rugged land. The flatness of Camas Prairie and the general abundance of surface-water supplies resulted in its early habitation and agricultural development. Hay production and grazing of beef and dairy stock are the major agricultural activities. Camas Prairie also serves as a gateway to the timbered upper Klickitat basin, and a substantial part of the area's population is involved in logging and other timber-related activities. Because of the accessible nature of Camas Prairie, most of the population of the Camas Prairie-upper Klickitat basin area is located on the prairie. The town of Glenwood (population 300) is the principal community.

The upper Klickitat basin lies north of the Klickitat County line. An area in excess of 360 squares miles, the upper basin lies entirely within the Federated Tribes of the Yakima Nation Reservation in western Yakima County (see Figure 1). Because of its political and geographic location, access to the upper basin is restricted and it is virtually uninhabited.

The upper basin is rugged and relatively high in elevation. The proximity of the area to the crest of the Cascade Mountains and its overall elevation assure abundant precipitation, much of which falls as snow and is retained as snowpack or glacial ice. The precipitation supports good timber growth and logging is the principal economic activity in the area.

Western Highlands

Between the White Salmon and Klickitat River valleys and south of Camas Prairie is a rugged area of limited population referred to here as the western highlands. Much of the highland's northern half is owned by the state or by private timber companies and is relatively undeveloped. The southern half is somewhat more open and contains numerous small farms and ranches. Timber production and ranching are the principal economic activities of the area.

Population of the western highlands is generally sparse, though less so in the south and west. No incorporated towns exist in the area; however, the communities of Appleton, Snowden, and Timber Valley are general population centers. In recent years, the western highlands has become popular for recreation homesites and some subdivision for this purpose is underway.

White Salmon River Valley

The White Salmon River valley in western Klickitat County is highly populated. The valley has a wide level floor suitable for development. Like the Klickitat River valley, the lower elevation of the White Salmon River valley results in a mild climate. The mild climate, flat valley floor, and abundant water have made the area desirable, especially for agriculture. Fruit, particularly cherries, peaches, pears, and apples, is grown in the lower end of the valley. In the upper end, beef and dairy herds are common and much of the land is used for grazing and/or hay production. Like other areas in western Klickitat County, the valley is also headquarters for logging operations in the surrounding hills with much of the timber going to mills in the Columbia River gorge.

Population in the White Salmon valley is relatively dense compared to the rest of the county. The community of Trout Lake is located near the upper end of the valley and the towns of Bingen and White Salmon near the mouth of the river. In addition, much of the valley is occupied by homesites, small ranches, and orchards, many of them around the communities of Husum and BZ Corners.

Columbia River Gorge

The Columbia River occupies a deep canyon along the southern margin of the county. At the eastern end of the county the river is only a few hundred feet lower than the plateau surface to the north; however, the gorge becomes progressively deeper to the west, with differences in elevation between the river and the undissected plateau areas in excess of 2000 feet. Differences in elevation between the river and parts of the Columbia Hills immediately to the north are, in some areas, greater than 3000 feet. This extreme topographic variation isolates the gorge from the rest of the county.

The dramatic geographic separation of the Columbia River gorge from the rest of the county necessitates treatment of the thin, 80-mile-long strip of the county that parallels the river as a separate geographic unit. The strip varies from only a few hundred feet in width to as much as 4-5 miles in some areas.

The depth and narrowness of the gorge has had a limiting effect upon development and population growth. In early years the mild climate and the importance of the river for navigation led to numerous small settlements along the banks of the Columbia. In many areas, orchards and truck farms were established on the flood plain and gravel bars. The establishment of the Columbia River power and navigation systems involved the construction of several large dams on the river, resulted in the disappearance of much of the usable land in the gorge, and forced a reduction in population. The dams have, however, provided irrigation water and hydroelectric power for agriculture and industry. Currently, population in the eastern half of the gorge is primarily centered around the town of Roosevelt, which is located on a wide bench about 150 feet above the river. In the central gorge area, orchards still operate near Maryhill, and a small population center is located here. To the west, the widest habitable location within the gorge occurs in the area of Dallesport, directly across the river from The Dalles, Oregon. Here, a flat bench, roughly equidimensional, supports the small communities of Murdock and Smithville and The Dalles municipal airport. West of Dallesport the communities of Lyle and Bingen occupy small flat areas adjacent to the confluence of the Columbia and the Klickitat and White Salmon rivers.

Like other valleys within the county, the mild climate and abundant irrigation water in the gorge facilitate agricultural production, principally irrigated wheat and fruit. Orchards at Sunnydale, Maryhill, North Dalles, and Bingen produce cherries, peaches, and apples. In addition to fruit orchards, some garden truck is grown in the lower areas near Bingen.

A small plateau, somewhat higher than the Columbia River, is located about halfway between the communities of Maryhill and Roosevelt and is known locally as Goodnoe Hills. The elevation of Goodnoe Hills above the river precludes irrigation, and dryland wheat is the principal crop. The steep hills north of the area have been useful only for cattle grazing.

The availability of inexpensive hydroelectric power has attracted some energy-dependent industries to the gorge. Among these, a large aluminum-refining plant operates near John Day Dam, east of Maryhill, and provides employment for many residents of Klickitat County.

GEOLOGY

Introduction

Because of the relationship between geology and water resources of any area, this study has involved investigation of the county's geology. As the total area of the county is in excess of 1800 square miles, geology was studied largely on a reconnaissance basis with detailed investigation reserved for areas of significance in terms of water use and water resource management. Parts of the county's geology have been studied in the past by Sheppard (1960, 1964, 1967), Newcomb (1969, 1970), Luzier (1969), Laval (1956), Schmincke (1964, 1967), Hammond (1973), and Waters (1955, 1961); however, no previous attempt has been made to study the geology on a county-wide basis.

Figure 14 presents the stratigraphic section present within the county and the informal stratigraphic nomenclature used in the report. On the extreme right-hand side of Figure 14 are four major geologic subdivisions which serve as the major mappable units for this report. Areal distribution of these four units is presented in Plates IV and V, and a discussion of the general stratigraphy of the county is presented below.

Older Volcanic and Volcaniclastic Rocks

The oldest rock units present in Klickitat County are a series of volcanic and volcaniclastic rocks which crop out near the western edge of the county. The sequence is only partially exposed and consists of both pyroclastic and epiclastic rocks with occasional interbedded basaltic and andesitic lavas. Although the two major rock types are discussed below, no attempt was made to differentiate the two in field mapping.

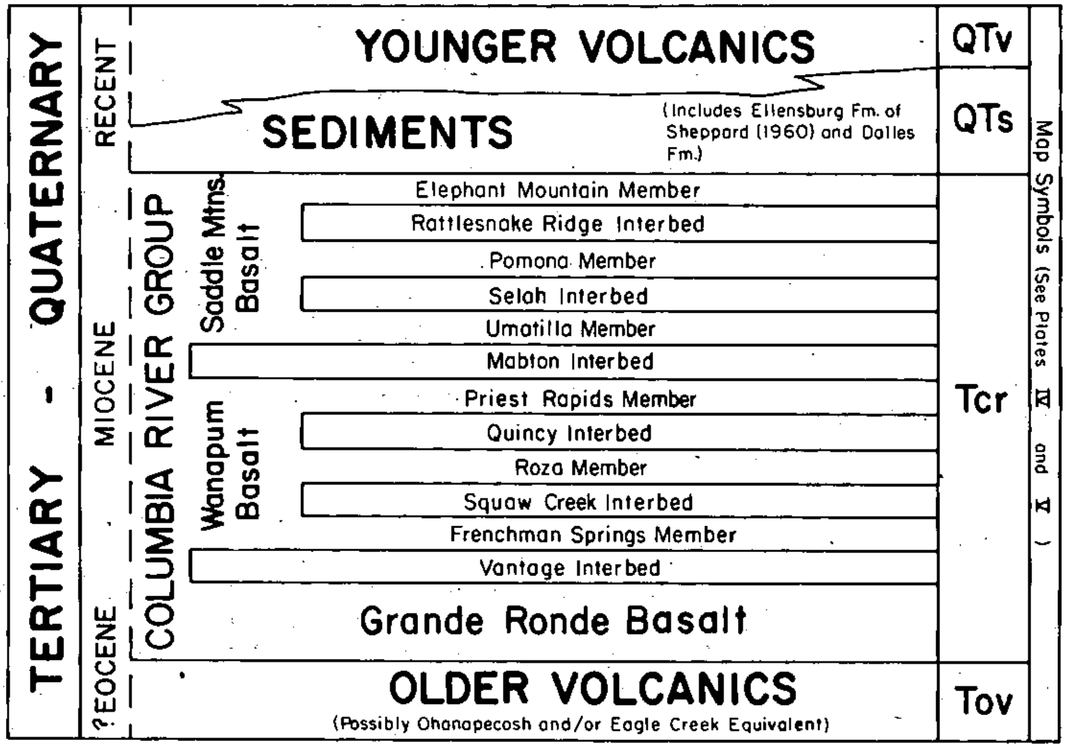

FIGURE 14. Informal stratigraphic nomenclature used in this report.

Volcaniclastic Rocks

The exposures of this older unit in Klickitat County consist primarily of pyroclastic units with a limited amount of epiclastic material. The pyroclastics consist mainly of thick sequences of tuff breccias with some interbedded tuff units. The tuff breccias contain clasts of andesite and pumice in an ashy matrix composed primarily of glass shards and small rock fragments which are usually altered and commonly are a green or red-green color. According to Wise (1970) and Fiske and others (1963), tuff breccias of the Ohanapecosh Formation were probably deposited as subaqueous pyroclastic flows. Evidence for this mode of formation includes not only the composition of these tuff breccias but also the fact that reworking of the material is evident in many of the breccia units.

In addition to the relatively abundant pyroclastic rocks, there are lesser amounts of epiclastic rocks, generally in the form of volcanic sandstones and some volcanic conglomerates. The sandstones occur as thin-bedded (less than 10 feet) layers of sand-sized volcanic detritus consisting mainly of rock fragments and plagioclase. In general, the sandstone is uncemented and friable and most of the material is deeply altered. Exposures of these epiclastic units within Klickitat County appear as thin layers beneath lava flows interbedded with the tuff breccias. The very nature of these epiclastic deposits and their close relationship with the interbedded lavas suggest that the sandstones and conglomerates were deposited subaerially.

Volcanic Rocks

Associated in limited quantity with the volcaniclastics are interbedded basaltic and andesitic lavas. Within the county area the total extent and thickness of individual flows was indeterminable; however, Wise (1970) reports similar flows in the Ohanapecosh Formation west of Klickitat County to be from 50 to 75 feet thick and traceable as far as seven miles.

These interbedded lavas appear gray, green-gray, or maroon and generally lack primary features such as columnar jointing and ramp structures. The lavas are generally hypocrystalline and commonly contain abundant small plagioclase phenocrysts (3-5 mm). In hand specimen, the basalts will occasionally resemble those of the Columbia River Basalt Group; however, major-element chemical analyses of the older basalts indicate higher silica and aluminum and lower titanium, iron, and calcium than the chemical types of the Columbia River Basalt Group (Table 1). Major-element chemistry of the older basalts also differs from that of the much younger olivine basalts, having higher silica and lower iron than the younger group.

TABLE 1: Major-element chemical analyses of selected volcanics, Klickitat County, Washington.

Element Oxide	Sample (Percent) A	B	C	D	E	F
SiO_2	59.67	58.55	53.36	50.37	48.70	53.04
Al_2O_3	16.30	17.27	14.82	13.93	16.49	17.59
TiO_2	1.23	0.78	1.68	2.97	2.89	1.68
Fe_2O_3	2.00	2.00	2.00	2.00	2.00	2.00
FeO	6.25	7.66	9.63	12.38	12.23	7.92
MnO	0.18	0.25	0.19	0.25	0.29	0.14
CaO	7.31	6.22	8.81	8.23	8.57	8.81
MgO	2.76	2.81	5.60	5.27	5.22	5.34
K_2O	1.77	0.89	1.16	1.45	0.89	0.72
Na_2O	2.23	3.14	2.45	2.59	2.72	2.52
P_2O_5	0.28	0.42	0.30	0.56	0.08	0.25

Sample Locations

A. From older volcanics in NW 1/4, SE 1/4, sec. 8, T. 6 N., R. 10 E., about 0.25 mi. west of forest service road and north of power line clearing.

B. From older volcanics in SW 1/4, SW 1/4, sec. 20, T. 6 N., R. 10 E., about 0.75 mi. up Sugar Bowl Butte road.

C. From flow of Grande Ronde Basalt in NW 1/4, NW 1/4, sec. 16, T. 4 N., R. 14 E., about 0.1 mi. south of junction of Klickitat and Little Klickitat rivers.

D. From flow of Frenchman Springs Member, same location as C.

E. From flow of younger olivine basalt in SW 1/4, SE 1/4, sec. II, T. 4 N., R. 14 E.

F. From flow of younger olivine basalt in Klickitat County Road Department Quarry. NE 1/4, sec. 2, T. 4 N., R. 16 E.

Occurrence

Exposure of these units is limited to the extreme western and northwestern edges of the county. The thickness and extent of the units is not well known because their vertical and horizontal limits are not exposed. The distribution of these units is masked by much younger volcanics of Mt. Adams and King Mountain as well as by the basalts of the Columbia River Group. Core drilling done as part of a potential reservoir investigation (North Pacific Consultants, 1960) on the east side of Trout Lake Creek encountered similar volcanic material, suggesting that parts of the units may be extensive in the subsurface.

The best exposure of the volcaniclastics occurs on the west side of a Forest Service road in Section 8, T. 6 N., R. 10 E., where 1200 feet of the units are exposed in a near-vertical cliff (Figure 15). However, neither the top nor bottom of this section is exposed and it is likely that the unit may

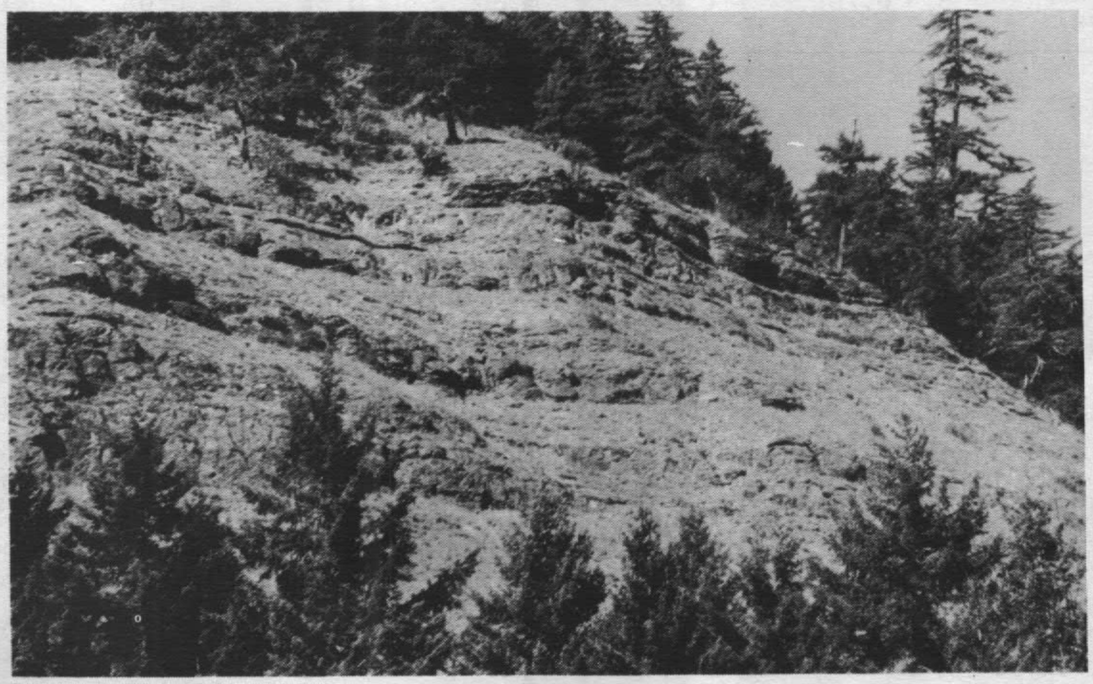

FIGURE 15. Exposure of older volcaniclastic rocks northwest of Trout Lake, Washington.

be substantially greater in thickness. Wise (1970) reports a section of similar lithology and stratigraphic position, approaching 19,000 feet in thickness, in the Wind River area west of Klickitat County.

Good exposures of older volcanics are present in a quarry just west of Trout Lake at the junction of State Highway 14 and a Forest Service road in the NE 1/4 sec. 21. T. 6 N., R. 10 E. Other exposures of this volcanic sequence are found in the Sugarbowl Butte area (Secs. 19 and 20, T. 6 N., R., 10 E.).

Age

The lack of a complete stratigraphic section and the generally poor exposure of this unit makes determination of age and stratigraphic position somewhat difficult. However, because of the similarity to the thick tuff breccia described by Fiske and others (1963) and Wise (1970), and because of recent work by Hammond (1973), it is suggested that the unit may be equivalent to part of the Ohanapecosh Formation as defined by Waters (1961). Although the volcaniclastics appear to resemble the Ohanapecosh, the interbedded basalts appear much less altered than those described by Fiske and Wise.

No fossil material for dating was found in any of the exposures within Klickitat County. Fiske and others (1963) assigned an age of Eocene to the Ohanapecosh based on plant fossils found by them and by Fisher (1957) in Mount Rainier National Park. Fossils collected by Wise (1970) in the Wind River area, west of Klickitat County, indicated an Oligocene age; no Eocene forms were present. Because it is impossible at this time to determine the stratigraphic relationship between the exposures in Klickitat County and those elsewhere, an age of Eocene to Miocene is assumed.

Columbia River Basalt Group and Related Sedimentary Interbeds*

The most extensive geologic units occurring in Klickitat County are the basalts of the Columbia River Group. These basalts form the high, dark brown to black cliffs along the sides of the Columbia River gorge and other major canyons in the area. The basalts underlie almost all of the county and are the county's principal ground-water source. The total thickness of the basalts is unknown, but exploratory drilling in the Rattlesnake Hills northeast of the county terminated at a depth in excess of 10,000 feet without completely penetrating basalt. While the Columbia River Basalt group may not be this thick in Klickitat County, the presence of increasingly younger flows from west to east indicates substantial increase in thickness occurring within the county. Maximum thickness may be on the order of several thousand feet.

Age

The age of the Columbia River basalt was for some time subject to question. Smith (1903) assigned a date of early to middle Miocene based on stratigraphic relationships in the Yakima Valley. Waters (1955) later reported the occurrence of fresh-water mollusks in sediments interbedded in the upper part of the basalt sequence to which an age of Pliocene was assigned. Later work by Sheppard (1960) on diatoms from exposures north of Satus Pass

*In order to maintain stratigraphic continuity in this section, sedimentary units interbedded with basalts of the Columbia River Group will be discussed in their proper sequence. The sediments are not part of the Columbia River Basalt Group and have been assigned by some to the Ellensburg Formation; however, for reasons which will be discussed later, the Ellensburg Formation designation is not used in this report.

indicated an age of early Pliocene. Recently, work by Berggren and Van Couvering (1974) has resulted in the re-establishment of the Miocene-Pliocene Boundary as no older than 5.3 million years. As a result, potassium-argon dates and palentologic data indicate that eruption of the entire Columbia River Group occurred within the Miocene (Swanson and others, in press).

The large number of individual units recognized within the Columbia River Basalt Group and the importance of this group to the hydrology of the county, necessitate a brief stratigraphic discussion of the Columbia River Basalt Group and related interbedded sediments. The nomenclature used for the basalt units is that proposed by Swanson and others (in press), and is presented in Figure 14.

Grande Ronde Basalt

The Grande Ronde Basalt is made up of an undetermined number of flows which, in some areas of the Columbia Plateau, total several thousand feet in thickness. Grande Ronde basalts are typically massive, dense, finely crystalline, and normally aphyric. Upon close examination, however, many Grande Ronde flows are found to contain microphenocrysts of plagioclase and pyroxene in varying amounts. Investigations of major-element chemistry indicate that the Grande Ronde Basalt is significantly different from other basalts in the Columbia River Group and warrant the establishment of a separate chemical type (Wright and others, 1973).

Because of their finely crystalline, uniform nature, Grande Ronde flows commonly outcrop as massive flows 100 to 200 feet thick and are often characterized by a close, hackly jointing pattern. Well-developed columnar jointing in the colonnade is generally lacking. Thick vesicular flow tops often cap the massive flows.

Surface exposure of the Grand Ronde Basalt is limited within Klickitat County. Known exposures are restricted to the deeper parts of the Klickitat River and Rock Creek canyons and to the exposed central parts of some of the major anticlinal structures, particularly in the west and southwest parts of the county. In spite of their limited surface exposure, Grande Ronde basalts are likely present in the subsurface throughout much of the county.

Vantage Interbed

Directly overlying the Grande Ronde Basalt is a sedimentary interbed which is correlative with the Vantage sandstone described by Mackin (1961). Within Klickitat County the interbed exhibits considerable variation in composition. In the Rock Creek canyon it consists predominantly of well sorted, fine-grained micaceous and tuffaceous sands (Figure 16). To the west in the

FIGIRE 16. Vantage interbed overlain by basalt of the Frenchman Springs Member along Goldendale-Bickleton Road in Rock Creek Canyon, Klickitat County, Washington.

Klickitat River canyon it consists of a large basaltic boulders and cobbles in a tuffaceous matrix.

Like most interbeds, the Vantage is easily eroded. Thus its known exposures are limited, occurring mainly in road cuts or other recent excavations. Known exposures of the Vantage interbed do not exceed 20 feet in thickness and are limited to the Klickitat River, Rock Creek, and Columbia River valleys. It is likely, however, that the interbed is exposed in some of the major anticlinal structures elsewhere in the county.

Wanapum Basalt

Flows from the Wanapum Basalt are well exposed in Klickitat County, particularly in the western and central two-thirds of the county. Wanapum flows commonly exhibit a greater lithologic variation than those of the Grande Ronde Basalt, and for this reason it is easier to define and trace individual flows or groups of flows of the Wanapum Basalt. A brief description of the units within the Wanapum Basalt is presented below.

Frenchman Springs Member: Resting directly upon the Vantage interbed and lowermost in the Wanapum Basalt is a group of flows named by Mackin (1961) as the Frenchman Springs Member. Frenchman Springs flows are characterized by fine crystallinity and a generally uneven distribution of plagioclase phenocrysts. The variable distribution of phenocrysts is a characteristic of Frenchman Springs flows, and lateral tracing of the flows reveals considerable variation in phenocryst density over short distances. In addition to their variable density, phenocrysts in the Frenchman Springs basalts are often clotted in large glomerocrysts. Within Klickitat County the phyric nature of the Frenchman Springs Member appears to be restricted to the lower flows. In many areas within the county, the upper flows exhibit relatively few phenocrysts and the uppermost flow is often aphyric.

Individual Frenchman Springs flows are generally thick and massive with large, well-developed columns, particularly in the lower part of the member. Individual flow thicknesses vary within the county but commonly exceed 100 feet.

Exposures of the Frenchman Springs flows occur over large areas of the county. Much of the basalt exposed in the west and central parts of the county, including many of the flows exposed in the Columbia River gorge, and Klickitat River canyon is assigned to the Frenchman Springs Member.

Squaw Creek Interbed: Mackin (1961) described a diatomite bed that overlies the Frenchman Springs Member and called it the Squaw Creek Diatomite. Within Klickitat County no interbed was found between the Frenchman Springs and overlying Roza members. However, in the Roosevelt area, a diatomite bed occurs between the Frenchman Springs and Priest Rapids members which may be, in part, stratigraphically equivalent to the Squaw Creek interbed.

Roza Member: Overlying the Frenchman Springs Member is a distinctive flow named the Roza Member by Mackin (1961). The Roza is a dense basalt of medium crystallinity which contains abundant plagioclase phenocrysts. Unlike similarly appearing flows within the Frenchman Springs Member, the Roza has a remarkably uniform distribution of phenocrysts throughout its entire extent. In addition, the phenocrysts tend to be individually distributed rather than as glomerocrysts typical of Frenchman Springs flows.

The Roza Member is relatively thin, generally less than 100 feet in thickness, and lacks good columnar jointing. The unit is often highly fractured which facilitates relatively rapid weathering. Because of its tendency to weather readily, exposure of the Roza within the county is poor.

The extent of the Roza within Klickitat County is not well known. It appears that the flow is present over much of the county; however, evidence suggests that it might not be present north and west of the confluence of the Klickitat and Little Klickitat rivers. The Roza crops out frequently east of the Little Klickitat River canyon and is found near the surface as far east as Rock Creek canyon. East of the canyon, however, the presence of flows of the Saddle Mountain Basalt indicate that, if present, the Roza is buried at considerable depth. Examination of a section near Roosevelt reveals no Roza Member present, and it is quite possible that the flow may not be present in the subsurface over much of the eastern third of the county.

Quincy Interbed: An interbed similar to one designated as the Quincy diatomite by Mackin (1961) is present throughout most of Klickitat County as tuffaceous sand and silt. The interbed rarely exceeds 5 feet in thickness but often is associated with a substantial pillow-palagonite complex formed at the base of the overlying flow (see Figure 17). In the Roosevelt area a thin diatomite bed (1-2 feet) is present between the Frenchman Springs and Priest Rapids members and may be equivalent, in part, to the Quincy interbed.

Priest Rapids Member: The uppermost sequence of flows included in the Wanapum Basalt is the Priest Rapids Member (Mackin, 1961). Basalts of the Priest Rapids Member are often distinctive as they are commonly coarsely-crystalline and often glassy in appearance. In contrast to the underlying Roza Member, Priest Rapids flows are commonly aphyric. Individual flows are dense, massive, and often exhibit well-developed columnar jointing. In the type section Mackin described four Priest Rapids flows with a combined thickness

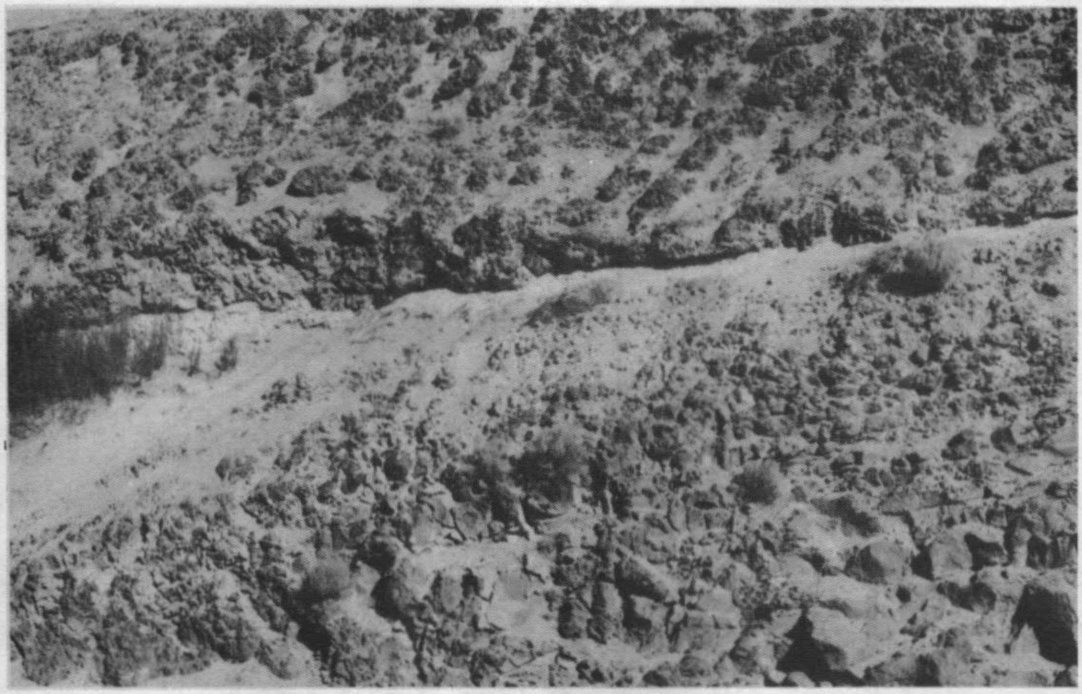

FIGURE 17. Contact of Priest Rapids and Roza members along State Highway 14 near Maryhill, Washington. Thick pillow-palagonite of Priest Rapids flow overlies thin interbed and Roza Member.

of about 220 feet. However, within Klickitat County, never have more than two flows been found and the total thickness ranges between 100 and 200 feet.

Exposures of the Priest Rapids Member are generally limited to the central Columbia gorge and to local areas in the central part of the county. Exposures of Priest Rapids flows are common in the Klickitat, Rock Creek, and Columbia River valleys.

Mabton Interbed: In the southerwestern part of the Columbia Plateau, the Wanapum and Saddle Mountain basalts are separated by a substantial tuffaceous interbed named, by Laval (1956), as the Mabton interbed. In most areas the interbed consists of tuffaceous sands and silts and massive tuffs. In the extreme east and southeastern part of the county the interbed becomes more of a cross-laminated sandstone with associated small pebbles of andesite.

In the eastern end of the county the Mabton interbed ranges from 30 to 50 feet in thickness, although subsurface information suggests that substantial thinning of the unit may occur to the north and west. The Mabton interbed is present mainly in the subsurface with surface exposures occurring only where erosion has cut sufficiently deep into the stratigraphic section. In many of the canyons south and east of Bickleton the Mabton is easily recognized as a prominent bench in the otherwise near-vertical canyon wall.

Saddle Mountains Basalt

Above the Wanapum Basalt is a group of flows recognized as the final outpouring of Columbia River fissure eruptions. These flows, previously referred to as the upper Yakima basalt, have been called the Saddle Mountains Basalt by Swanson and others (in press). Flows of the Saddle Mountains Basalt are generally more limited in extent than those of the Wanapum or Grande Ronde basalts and are centered in and around the Pasco Basin. Several of the Saddle Mountains flows occur in eastern Klickitat County.

Umatilla Member: Overlying the Mabton interbed in most of the eastern third of Klickitat County is a very dense, massive basalt named the Umatilla Member (Laval, 1956). Laval included the Umatilla within the Priest Rapids Member; however, Schmincke (1964) later separated the flow based upon its physical characteristics and areal distribution. The Umatilla is commonly a massive, very finely-crystalline black basalt containing no phenocrysts. The flow normally exhibits poorly defined columnar jointing and, in many areas, has a thick vesiculated top. The dense, uniform nature of the Umatilla makes it more resistant to weathering than most flows and it often forms a substantial part of many of the steep canyon walls in eastern Klickitat County.

Exposures of the Umatilla Member are generally restricted to canyon walls in the area south and east of Bickleton. In these areas the thickness of the unit approaches 200 feet. In some areas, the Umatilla appears to consist of two separate flows while in others only one thick flow is evident.

Unlike most flows in the Columbia River Basalt Group the Umatilla Member is usually easily recognized in borehole geophysical logs. Crosby and others (1972) recognized that the Umatilla flow characteristically exhibited a high natural gamma response which facilitated the flow's identification in geophysical logs. The ability to identify the Umatilla Member in the subsurface greatly facilitates delineation of its areal extent within the county. Interpretation of borehole geophysical logs and surface exposures indicates that the Umatilla Member underlies much of eastern Klickitat County but pinches out between Cleveland and Rock Creek canyon to the west. The stratigraphic section at Rock Creek lacks evidence of the Umatilla Member but exposures of the flow do occur in Spring Creek canyon approximately 8 miles to the east. The southern extent of the Umatilla flow appears to coincide generally with the axis of the Swale Creek syncline. The flow has been traced south along Pine Creek canyon to a point near the center of Section 8, T. 4 N., R. 21 E., where it can be seen to pinch out. South of this location, in the Roosevelt area, the Umatilla Member is not present.

Selah Interbed: Overlying the Umatilla Member is a tuffaceous interbed which Schmincke (1964) has called the Selah. The term Selah has a somewhat confused history because Mackin (1961) used it to include all interbeds between the Roza and Pomona members. Schmincke suggested restricting the term to the interbed above the Umatilla (when the Umatilla is present) and above the Priest Rapids Member when the Umatilla is not present. This, however, creates some confusion with the underlying Mabton interbed. In this report the terms Mabton and Selah will be used to define the interbeds surrounding the Umatilla Member. When the Umatilla is not present, the interval will be referred to as the Mabton-Selah interbed.

The Selah is generally a silty tuff, bleached white-to-tan; however, Schmincke (1964) reports a vitric tuff to be present in some areas. Within the county the Selah is present as a thin interval on top of the Umatilla Member. The interbed ranges from 5 to 15 feet in thickness, generally thickening slightly toward the south. In the Roosevelt area where the Umatilla Member is not present, the Mabton-Selah interbed reaches a thickness of nearly 200 feet. A much thinner Mabton-Selah is present between the Pomona and Priest Rapids Members in the Lyle area of western Klickitat County.

Pomona Member: Overlying the Selah or Mabton-Selah interbed is a distinctive basalt flow named the Pomona by Schmincke (1964). The flow was originally named the Wenas basalt by Smith (1903), but the term was abandoned because of considerable confusion which developed from later work.

The Pomona Member is a dense finely-crystalline basalt with abundant, uniformly distributed plagioclase microphenocrysts. The microphenocrysts are generally 1 to 2 mm in size and are often found in glomerporphyritic clusters. Because of its unique appearance the Pomona is often readily recognized in the field.

The Pomona commonly exhibits small, well-developed columns, at least in part of the flow. In some areas the columns of the Pomona exhibit a distinctive undulating appearance that can be quite striking. Occasionally columns will be broken by evenly-spaced horizontal jointing which produces an abundance of polygonal blocks. Total thickness of the Pomona Member normally exceeds 100 feet, and information from geophysical logs indicates that it may approach 200 feet in some areas.

Exposure of the Pomona Member is relatively common in the eastern part of Klickitat County as the flow forms the gently dipping, undissected surface from Harrison Creek east to the Spring Creek Canyon-Sand Hill area. While occurrence of the Pomona is generally restricted to the area east of Rock Creek, it also appears in the Columbia River gorge along the southern edge of the county. Exposures within the gorge occur as far west as Lyle where Schmincke (1964) measured a section of Pomona totalling 100 feet.

Rattlesnake Ridge Interbed: Overlying the Pomona Member is the Rattlesnake Ridge interbed (Schmincke, 1967). Rattlesnake Ridge sediments are predominantly tuffaceous with some micaceous sands and silts. The interbed is exposed in the county only where erosion or excavation has cut away the overlying Elephant Mountain basalt. The interbed is generally 20 to 50 feet thick. The Rattlesnake Ridge is commonly restricted to the Alderdale, Dead Canyon and Glade Creek areas in the extreme eastern part of the county; however, isolated exposures of the interbed have been found in the upper reaches of Squaw Creek canyon west of Cleveland (Figure 18).

Elephant Mountain Member: The youngest basalt of the Columbia River Group exposed in Klickitat County is the Elephant Mountain Member. Originally two flows, the Elephant Mountain and the Ward Gap, were defined by Schmincke; however, Swanson and Wright (1976) later showed the two to be identical in composition and thus the term Ward Gap was dropped. The Elephant Mountain member is finely crystalline and sparsely porphyritic. In general, the

FIGURE 18. Elephant Mountain Member overlying Rattlesnake Ridge interbed along Goldendale-Bickleton Road, west of Cleveland, Washington.

phenocrysts are plagioclase with lesser amounts of pyroxene and phenocrysts increase in number near the bottom of the flow. The Elephant Mountain Member is relatively thin, generally less than 50 feet, and exhibits poorly developed columnar jointing. Associated with the columnar jointing are abundant cross fractures which give the flow a hackled appearance similar to that of many Grande Ronde flows. The fractures allow the flow to weather to rubble of roughly equidimensional angular blocks.

Exposure of the Elephant Mountain Member is generally restricted to the extreme eastern end of the county where it is at, or near, the surface in many areas. Because of its proximity to the existing topographic surface, it is questionable whether a complete section of the Elephant Mountain is present in the county. Isolated exposures of the Elephant Mountain Member also occur in Squaw Creek canyon, west of Cleveland (Figure 18).

Tertiary-Quaternary Sediments

Occurring in many areas of the county are sequences of sediments which vary in thickness and composition and which overlie the basalts of the Columbia River Group. The sediments are normally poorly indurated and quite susceptible to weathering; thus, their occurrence is restricted to topographically low areas or to areas where younger volcanics form a protective cap. Because of their highly variable nature, the sediments have been the source of many problems in the stratigraphy and geologic nomenclature of south-central Washington.

Distribution and Description

Sediments occupying a similar stratigraphic position occur in several areas within Klickitat County. In the Goldendale area and Little Klickitat River drainage, the sediments are poorly indurated, meta-quartzite-bearing conglomerates, gravels, and micaceous sands and silts. The sediments are usually poorly sorted and, although meta-quartzite accounts for 50-60% composition, andesites and basalts are also present in much lesser amounts (Sheppard, 1960). The matrix material is normally micaceous sand and silt; however, in a few areas, the matrix is highly tuffaceous. The sediments are quite noticeable in outcrop because of their bright brown to reddish brown color, due apparently to secondary ferruginous staining, and because when present, the meta-quartzite pebbles litter the immediate area.

Thickness of this sedimentary unit in the Goldendale area varies considerably. In some places, younger basalts can be found to overlie basalts of the Columbia River Group with little or no sediment present. In other places, exposures of 50 to 100 feet are common and drilling information indicates that thicknesses may reach 200 feet or more.

Because of the poorly indurated nature of these sediments, exposure in the Goldendale area is generally restricted to locations where erosion or construction has cut through the protective cap of younger volcanics. Good exposures of these sediments are found along U. S. Highway 97 between Goldendale and Satus Pass. Drilling information and exposure of similar sediments along the Goldendale-Glenwood road suggest that the sediments may be present beneath the younger volcanics over much of the area north and west of Goldendale.

Exposures of similarly-appearing deposits are present eastward from Goldendale to the Bickleton area. East of Rock Creek the sediments are nowhere overlain by younger volcanics and they appear to contain substantially greater percentages of basaltic and andesitic material. Mapping of these sedimentary deposits between Bickleton and Rock Creek revealed abundant meta-quartzite pebbles with relatively little fine matrix material. This suggests that erosion has removed the finer fraction and that the exposures represent a lag concentrate or even redeposition. Therefore, deposits in the Bickleton area may not be direct correlatives with those in the Goldendale area.

South of Goldendale, in the Swale Creek valley, similar sediments are exposed. Here, the sediments occupy a shallow synclinal basin and are generally not overlain by younger volcanics. However, in the southeast quarter of Section 28, T. 3 N., R. 15 E., a small tongue of younger volcanics from Haystack Butte appears to overlie the sediments. In the Swale Creek sediments meta-quartzite gravels are interbedded with tuffs and tuffaceous and micaceous sands (Figure 19). This arrangement suggests that the quartzite pebbles in the deposits may have been reworked to some degree. Total thickness of the deposits in the Swale Creek valley is unknown but a few wells drilled in the sediments penetrate thicknesses in excess of 200 feet.

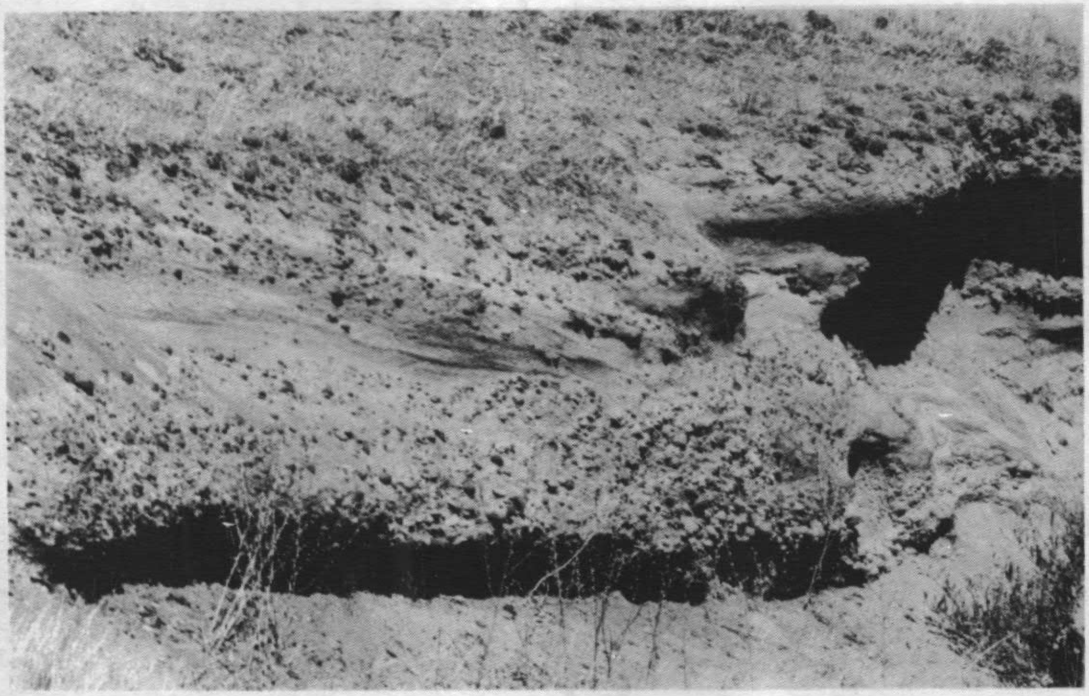

FIGURE 19. Tertiary-Quaternary sediments in Swale Creek valley, west of Warwick, Washington.

West and south of the Goldendale-Centerville area sedimentary deposits occupying a similar stratigraphic position have been called part of the Dalles Formation. In these areas the sediments contain few quartzite pebbles and are mainly volcaniclastics, predominantly basalt and andesite pebbles in a tuffaceous matrix. In some areas a welded tuff is present. Thickness of the Dalles Formation north of the Columbia River rarely exceeds 100 feet; however, exposures south of the river approach 1800 feet in thickness (Newcomb, 1969).

Age and Stratigraphic Nomenclature

Age, stratigraphic relationship, and nomenclature of these sedimentary deposits in the county pose some questions. The similarity of the sediments exposed in the Goldendale area with those of the Yakima area led Waters

(1955), and later Sheppard (1960), and Luzier (1969), to assign them to the Ellensburg Formation. Newcomb (1969) assigned sediments of a similar stratigraphic position in the southwestern part of the county to the Dalles Formation, based upon their lithologic similarity with the Dalles Formation south of the Columbia River. The sediments in Swale Creek valley appear to occupy a similar stratigraphic position, but both Luzier and Newcomb were reluctant to assign them to either the Ellensburg or the Dalles formations. Furthermore, exposures have been found in which sediments containing metaquartzite pebbles are found between flows of younger volcanics.

Because of the confusing stratigraphic relationships and the existence of at least two well-established geologic names, no effort is made in this report to redefine ages or names of these disparate sedimentary deposits. Instead, the term Tertiary-Quaternary sediments is used to include all of these deposits.

The uncertainty associated with the stratigraphic relationships of these sedimentary deposits also poses problems for determination of age. Newcomb (1966) suggested an age of early-to-middle-Pliocene for the Dalles Formation, and this age would seem plausible for areas where the sediments can be seen to conformably overlie the Columbia River basalt. In areas where an unconformable relationship exists and where sediments are interbedded within flows of younger volcanics, a much more recent age is suggested. Thus, a general age range of Pliocene to Recent is used herein to include all units mapped as Tertiary-Quaternary sediments.

Tertiary-Quaternary Volcanics

Extending over much of the western half of Klickitat County is a sequence of volcanics younger than the Columbia River Basalt Group. These volcanics are highly variable in composition and distribution, and the stratigraphic relationship of individual units is not well known. In general, the volcanics consist of two groups: one is predominantly olivine basalt and the other includes rhyolites, dacites, and andesites.

Olivine Basalt

The younger olivine basalts are, in most cases, easily distinguished from the basalts of the Columbia River Group. In contrast to the uniform, dark, generally aphyric flows of the Columbia River Group, the younger olivine basalts commonly appear as thin gray flows, often highly phyric. Flow thickness is generally 15-20 feet, but ranges from as little as 5 feet to as much as 50 feet. The basalts are generally holocrystalline and are commonly coarse-grained. Sheppard (1960) noticed that two distinctive textural types were discernible in the field. One is typified by an intergranular texture and is finely-crystalline. The other is characterized by a well-developed diktytaxitic texture. Both textural types are commonly phyric and contain abundant olivine and plagioclase phenocrysts. Sheppard reports that the type characterized by diktytaxitic texture commonly exhibits flow alignment of plagioclase phenocrysts. Olivine phenocrysts in both types are commonly altered to iddingsite. Comparison of major-element chemistry of the olivine basalts and basalts of the Columbia River Group reveal distinct differences (see Table 1). The younger olivine basalts are characterized by higher aluminum and a lower iron and phosphorous content than the Columbia River types.

Other Volcanics

Occurring less frequently than the olivine basalt, the dacite, rhyolite, and andesite flows are limited in areal extent. The dacites are commonly pale tan, purplish-tan to gray and contain phenocrysts of plagioclase, olivine, and hornblende. The rhyolites generally exhibit flow banding with alternating light and dark pale bands. The rhyolites are porphyritic but generally contain less than 3 percent phenocrysts (Sheppard, 1960), normally plagioclase. Quartz, magnetite, and zircon are also present. Sheppard (1960) also reports rare inclusions of basalts of the Columbia River Group and younger olivine basalts in the rhyolite flows.

In addition to the dacites and rhyolites, several andesite flows have been recognized by Sheppard (1960, 1964, 1967). The andesites are commonly light gray with flow-aligned phenocrysts of plagioclase and hypersthene. Thickness of the flows is generally less than 100 feet. However, Sheppard (1967) reports an andesite flow in the upper Klickitat River canyon that is in excess of 350 feet thick.

Occurrence

Plates IV and V show the distribution of the younger volcanics in Klickitat County. As can be seen, the volcanics are generally restricted to the northern and western parts of the county. The volcanics form part of the Simcoe Mountains, north of Goldendale, as well as King Mountain and Camas Prairie near Glenwood. In the Goldendale area, the Little Klickitat River appears to mark the southern boundary of the younger volcanics except for local volcanic centers at Lorena and Haystack Buttes and some exposures south of the Little Klickitat-Klickitat River confluence. No exposure of younger volcanics have been found east of Rock Creek. Most of the area shown as Tertiary-Quaternary volcanics is younger olivine basalt; however, some dacites, rhyolites, and andesites are also present.

In general, individual flows are of limited extent. Sheppard reports flows extending as much as 14 miles; however, most appear to be much more restricted. Many flows occur as channel fillings in the larger canyons and in smaller drainages. Figure 20 illustrates this channel filling on a limited scale in which younger volcanics cut into a Priest Rapids flow. Of two younger basalt flows which are present here, one is entirely restricted to the channel. In addition, both the Klickitat and White Salmon River canyons are partially filled with younger volcanics. These valley-filling flows clearly indicate that the major drainages were well established by the time of the extrusion of the younger basalts.

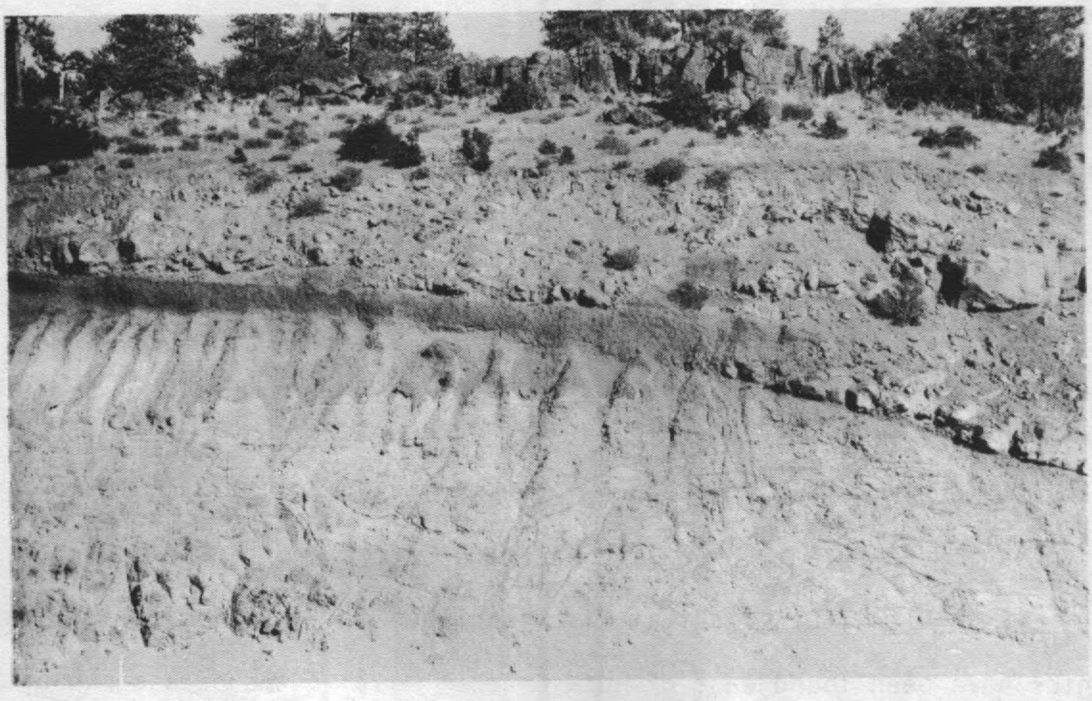

FIGURE 20. Younger olivine basalt filling channel cut into Tertiary-Quaternary sediments and weathered Priest Rapids Member along U. S. Highway 97, north of Goldendale, Washington.

Age

The age of the younger volcanics is not well known. Stratigraphic relationships indicate that the volcanics are younger than Wanapum Basalt and at least the Pomona Member of the Saddle Mountains Basalt. Potassium argon dates obtained by Shannon and Wilson, Inc. (1973), on the younger volcanics indicate absolute dates from 4.5 to 0.03 million years. These dates and the overall stratigraphic relationships would indicate an age span of Pliocene to Recent. Work by Sheppard (1960, 1964), Hammond (1973), and Shannon and Wilson seem to indicate a general decrease in age of the younger volcanics from east to west.

Unconsolidated Deposits

In many areas of the county, bedrock is overlain by unconsolidated sedimentary deposits. In most places these deposits consist of gravels, sands, and silts of glacial and/or glaciofluvial origin. While most occurrences of these deposits are restricted to the Columbia River gorge, deposits also occur in the Camas Prairie area and in the eastern part of the county.

Unconsolidated deposits near the eastern margin of Klickitat County consist mainly of slack-water silts and occasional gravel deposits related to glacial flooding. The slack-water silts were apparently deposited up to an elevation of 100 feet in the eastern half of the county and isolated deposits of these silts persist in protected back-water areas of the canyons. In addition to the slack-water silts, ice-rafted erratics of granite and metaquartzite can also be found.

Unconsolidated gravels, sands and silts are present at many localities in the Columbia River gorge. Most of these deposits are of limited areal extent, and thicknesses seldom exceed 50 feet. In several places between Lyle and Bingen the sediments were quarried for road building and dam construction in the gorge. In both the Columbia River gorge and the eastern part of the county these sediments are of limited extent and distribution. In the Camas Prairie area the unconsolidated sediments are much more extensive, and Cline (1976) reports that thicknesses near the southwestern end of the prairie exceed 160 feet. Because of their thickness and extent, the unconsolidated sediments in the Camas Prairie area are an important groundwater source.

With the exception of the Camas Prairie area, the unconsolidated sediments are highly variable in occurrence and relatively unimportant to the county's water resources. For these reasons their distribution is not shown on Plates IV and V; however, the section on ground-water occurrence contains a discussion of their importance to the Camas Prairie area.

Structure

Introduction

The relationship of geologic structure to water distribution and occurrence has long been recognized. Newcomb (1961) illustrated the importance of this relationship for basalt aquifers and suggested that faults and folds within the basalts can act as either barriers or conduits for the movement of ground water. It is evident, therefore, that any analysis of water resource distribution would not be complete without an understanding of the principal geologic structure of the study area.

Geologic mapping was necessarily of a reconnaissance nature, particularly in the western third of the county where vegetative cover limits outcrop and obscures structural relationships. Special attention was given to the Goldendale-Centerville area because of the relatively high ground-water use in that area. Field mapping revealed that in most of the county, orientation of the major structures is in one of two dominant directional groups. One group has a predominant east-west trend, while the other group is oriented northwest-southeast. Major structural features are shown on Plates IV and V, cross sections are presented in Plate VI, and a discussion of the two general groups follows.

East-West Structures

The northern and southern boundaries of Klickitat County are generally defined by major anticlinal structures. The Horse Heaven anticline to the north and the Columbia Hills anticline to the south, form topographically prominent ridges which extend along much of the county's margin. The Horse Heaven anticline forms a linear ridge, the crest of which is the southern boundary of the Yakima Indian Reservation. The fold is broad and asymmetrical, with the steeper flank to the north. The southern flank of the anticline forms a gently sloping dip surface which underlies much of the county. The western part of the anticline first appears in a northeast-southwest trending ridge which begins near Gilmer Flat and extends along the south side of Camas Prairie. Just east of the intersection of the Klickitat River and the anticlinal axis, the strike of the structure becomes more easterly with the anticlinal crest creating much of the relief of the Simcoe Mountains north of Goldendale. East of the Satus Pass area the structure plunges to the east and near Bickleton the primary axial element dies out. However, north of this plunging axis another anticlinal axis develops and carries to the northeast out of Klickitat County. This new anticlinal axis forms the extension of the Horse Heaven anticline east of Klickitat County. The two axes are separated by a synclinal valley, north of Bickleton, in which Pine Creek flows.

To the south, the Columbia Hills anticline follows much the same trend as the Horse Heaven structure. The westernmost exposure of the Columbia Hills anticline within the county is on the north side of the Columbia River gorge near Lyle. The anticline is breached by the Columbia River here, where it was originally recognized and named the Ortly anticline by Williams in 1916 (see Figure 21). To the northeast the trend of the anticline becomes more easterly and parallels the Columbia River valley. Like the Horse Heaven structure to the north, parts of the Columbia Hills anticline appear to die out but are replaced by similar-trending structures in the area east of Rock Creek. The eastern continuation of this structural trend has been called the Alder Ridge anticline by Newcomb (1971).

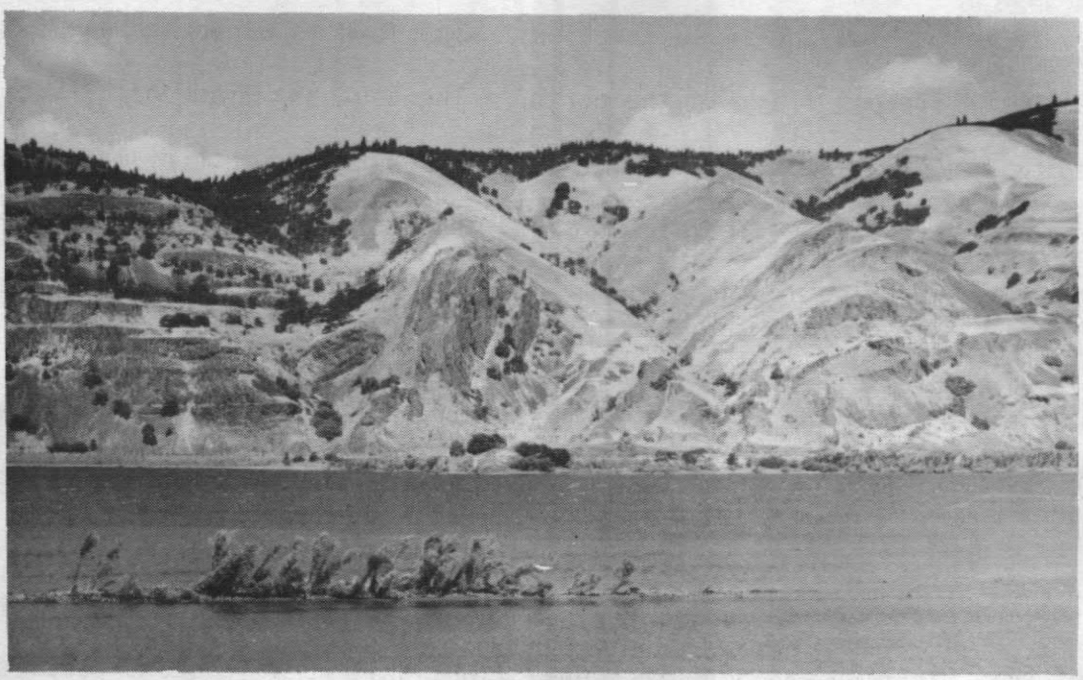

FIGURE 21. Columbia Hills anticline near Lyle, Washington.

The Columbia Hills anticline is much steeper than the Horse Heaven structure, particularly on its south flank south of Goldendale. The steepness of this southern flank led Hodge (1931) to suggest faulting rather than folding as the cause of the Columbia Hills. However, subsequent work (Newcomb, 1969) has shown it to be primarily a folded structure although there is probably substantial faulting associated with it.

Lying between the Columbia Hills and Horse Heaven anticlines is the Swale Creek syncline. The syncline is asymmetrical with its axis located at the base of the steeply-dipping north flank of the Columbia Hills anticline. South of Centerville the synclinal axis forms a natural trough in which Swale Creek flows. The syncline parallels the Columbia Hills structure, and near the intersection with Rock Creek the synclinal axis is offset in a manner similar to the Columbia Hills anticline.

Throughout much of the county there are smaller structures with trends and character similar to the major east-west structures. Between the Swale Creek and Little Klickitat River valleys is a broad, flat anticline to which Luzier applied the name Horseshoe Bend anticline. The structure is apparent for only a few miles and it plunges out to the northeast near the southwest corner of Goldendale. A shallow syncline parallels the anticline to the north. Similarly, between Bickleton and Cleveland in the eastern part of the county, a small anticline is present which parallels the Horse Heaven structure to the north. This small anticline appears to plunge beneath the surface at the edge of the town of Bickleton. The presence of these smaller structures is not particularly surprising as the major stresses that resulted in the formation of the Horse Heaven Hills and Columbia Hills likely produced many smaller, similar-trending features throughout the county.

Near the west end of the county, deformation becomes more severe and the presence of these minor structures is more apparent. In the southwest portion of the county several folds are present, the strike of which parallels the strike of the western extension of the Horse Heaven and Columbia Hills anticlines. These structures include the Bingen anticline, the Mosier syncline and an unnamed syncline which is occupied by Rattlesnake Creek, east of Husum. Like similar structures to the east, the folds appear to plunge and disappear to the northeast, west of the Klickitat River canyon.

Northwest-Southeast Structure

Superimposed upon the major east-west structures in the county are a series of northwest-southeast trending folds which seem to occur with regularity throughout the central part of the county. These structures were first reported by Sheppard (1960), who noticed that several of the Simcoe Mountain volcanic centers appeared to line up along northwest-southeast lineations. Associated with these lineations are a series of discriminate topographic protrusions which appear as small rounded domes on the gently dipping surface near the axis of the Swale Creek syncline. Although the domes appear to be isolated, they tend to occur along linear trends suggestive of some measure of integration. The domed features are most noticeable in the Columbia River basalt but also occur in the younger volcanics, generally near their southern margin. Sheppard (1960) attributed the structures to faulting and suggested that the topographically positive features associated with the lineations might be due to lava doming. Newcomb (1969) and Luzier (1969) later mapped several of these features and displayed them generally as inferred strikeslip faults.

In an effort to better define these features, flow-by-flow mapping was done in the Goldendale-Centerville area. The specific basalt flows involved are the uppermost Frenchman Springs, the Roza, and the Priest Rapids members. Mapping revealed that the central part of these domed structures was Frenchman Springs basalt and that the center was surrounded by progressively younger flows. In areas along the lineation where no topographic variation existed, the surface flow, generally Roza or Priest Rapids, was found to extend uninterrupted across the projected trend of the lineation. With a single exception, no direct evidence of faulting was found. The exception is in a small quarry in the NW 1/4 of Section 31, T. 4 N., R. 16 E, near the base of one of these domal features, locally referred to as Snipes Butte. In the quarry wall a 2-foot wide gouge zone is present. The zone cuts the uppermost Frenchman Springs flow but no evidence of vertical offset could be found. The lack of discernible offset and the size of the fault zone suggest that it may be a minor fault of a release nature associated with folding of the butte. Mapping in the area of Warwick, for which the Warwick fault (Newcomb, 1969) is named, produced no direct evidence of faulting; however, the topographic prominences strongly indicate folding. Study of the Goldendale fault (Luzier, 1969) resulted in a similar conclusion. Accordingly, the structures are shown as folds on Plates IV and V. Because the structures appear to exhibit a degree of linearity, the small domes are connected with a dashed line to indicate the general trend of the lineament.

The presence of linear trends of small disparate folds is not restricted to the immediate Goldendale area. East of Goldendale topographically prominent Luna Butte appears to be on a similar line of such features. East of Rock Creek a similar lineament connects a series of topographically prominent buttes which includes Quartz and Harrison buttes. Regional mapping (Shannon

& Wilson, Inc., 1973) suggests that lineament may extend south across the Columbia River into Oregon where it is known as the Arlington-Shuttler Butte lineament. East of this lineament, similar features do not appear to be present and the gently-dipping south limb of the Horse Heaven anticline does not show secondary structures with a northwest-southeast lineation. West of the Klickitat River, similar folded lineations are not apparent. However, the area is heavily forested and topographically rugged so such features are less likely to be apparent. Sheppard (1967) did infer the presence of several faults associated with stream drainages near Husum which have a similar northwesterly trend.

Age of Deformation

The actual age and relationship of structural deformation in this area are not well known. Basalts of the Columbia River Group appear to be folded in the major east-west structures and are unconformably overlain by the younger volcanics. This relationship would suggest that the major folding must have taken place in the interim. Absolute dates for the younger volcanics, obtained by Shannon and Wilson, Inc. (1973), range from 4.0 to 0.03 million years, which would suggest that the major east-west folds may have developed in the Pliocene. Whether the northwest-southeast structures developed at the same time is not known; however, the younger volcanics are implicated in the folding in at least two places and there is evidence which indicates the structures may have been involved in two separate stages of folding. These data suggest that development of the northwest-southeast structure may have been contemporaneous with the east-west ones and that further folding of these northwest-southeast structures took place after the extrusion of the younger volcanics.

Geology

Geologic History

From the relationship of geologic units within Klickitat County and information about similar units from other areas of Washington and Oregon, a general geologic history can be inferred.

The geologic record prior to Tertiary time is unknown. However, the presence of Eocene volcaniclastics along the western edge of the county and in the Cascade Mountains indicates abundant extrusion of volcanics during the early Tertiary. The nature of the extrusive material indicates that it was deposited under water, probably in inland lakes.

Following this early Cascade volcanism, fissure eruptions occurred in the Columbia Plateau area and great volumes of basalt of the Columbia River Group were extruded over much of what is now eastern Washington and Oregon. During the later stages of Columbia River basalt extrusion, some structural deformation and increased Cascade volcanic activity are evidenced in the areal restriction of the later basalt flows and the increase in interbedded tuffaceous sediments.

As the Columbia River volcanism decreased, Cascade volcanism apparently increased and a large amount of pyroclastic debris was distributed eastward and southward from the Cascades. Toward the end of this renewed Cascade volcanism much of the major structural deformation was apparently beginning, which ultimately resulted in formation of many of the east-west structures east of the Cascades and some of the northwest-southwest structures. Contemporaneously with this deformation, streams began to establish their present drainage patterns.

Following the major period of deformation, renewed volcanism covered parts of the county with younger basalts and andesites, culminating in the extrusion of the recent Mt. Adams volcanics. Concomitant with Simcoe Mountain and recent volcanism, renewed structural deformation along a northwest-southwest orientation was also developed.

SURFACE-WATER RESOURCES

Introduction

Although a discussion of surface water resources normally includes standing bodies of water, the virtual absence of lakes and man-made reservoirs within Klickitat County limits consideration to rivers and streams.

Discussion of surface waters is divided into three major sections. First a brief overview of the county's surface water is presented, followed by a presentation of relevent data. Finally, the data are discussed for each of the major drainage basins.

General Characteristics

Like its climate, the county's surface-water resources exhibit considerable variation from east to west. These variations facilitate categorizing the major streams into three general types. Streams in the eastern half of the county are intermittent. When flowing, these streams normally display low daily discharges, but discharges may vary over several orders of magnitude for a limited duration. Discharge variation is a function of the high runoff potential of the land surface in the drainage basins. The variation produces flashy streams characteristic of an arid or semiarid climate. Streams of this type derive from direct runoff and flow only during high-precipitation months.

A second type of stream present in Klickitat County is the perennial stream. This type commonly has a very low discharge throughout the year but annual discharge variation is less dramatic than that of the first type. The stream source is also direct runoff; however, some of the precipitation is retained in the form of snowpack which produces a more gradual release during spring and early summer. Differences between peak runoff and low flow are more gradational than in streams of the first category, indicating a substantial contribution from bank and basin storage. Streams in the central part of the county, particularly the Little Klickitat River, are streams of this type.

Streams in the western part are representative of a third stream type. This type is characterized by streams having little discharge fluctuation throughout the year and having a higher ratio of discharge to drainage area than either of the other two types. Streams of this type are fed by direct runoff; however, much of the precipitation is captured in the form of snow at higher elevations, and gradual melting coupled with ground-water discharge sustains a relatively high flow throughout the year. Streams of the third type are, of course, most desirable as irrigation sources because of their sustained flow through the low-precipitation months.

Basic Stream Flow Data

Most of the quantitative information on surface-water resources is in the form of stream discharge measurements. The measurements provide a measure of the flow of a stream past a given point. Within Klickitat County, three types of stream measurements have been made. The most complete data are acquired with a continuously recording gaging station. At such a station, discharge information is recorded continually (generally graphically) providing an uninterrupted record of the stream flow. Because the discharge of a stream varies continually, the daily discharge is normally presented as the mean for a given 24-hour period. Evaluation and presentation of gaging station information in this report is based on mean daily discharge unless otherwise noted.

Other types of stream measurement include miscellaneous discharge measurements and crest-stage measurements. Miscellaneous measurements are instantaneous measurements made by field personnel at selected locations on streams. These measurements provide instantaneous discharge values and furnish flow information on streams lacking continuous recording stations or at ungaged locations on gaged streams. Crest-stage measurements record the maximum discharge of a stream during selected time periods through the mechanism of a high water mark on a calibrated gage. Crest-stage measurements provide only a maximum discharge value.

All streamflow information used in this report was collected by the U. S. Geological Survey as part of a program to obtain information on the nation's surface-water supplies. Crest-stage and miscellaneous discharge measurements made within the county and in the upper Klickitat River basin are presented in Appendix A. Locations of the recording sites are shown on Plates I, II, and III.

Bar Chart of Stream Gaging Stations

The period of record for all stations within Klickitat County and in the upper Klickitat River basin, for which continuous discharge records are available, is presented in Figure 22. Included in Figure 22 are the U. S. Geological Survey location numbers for each gaging station. The location numbers provide an abbreviated method of reference to a specific gaging station and are used to identify each station on Plates I, II, and III.

Figure 22 indicates that most gaging stations in the western half of the county have been operated in the White Salmon and Klickitat River drainages. For most of these stations, the period of operation was relatively short. The longest continuous record appears to have been made on the Klickitat

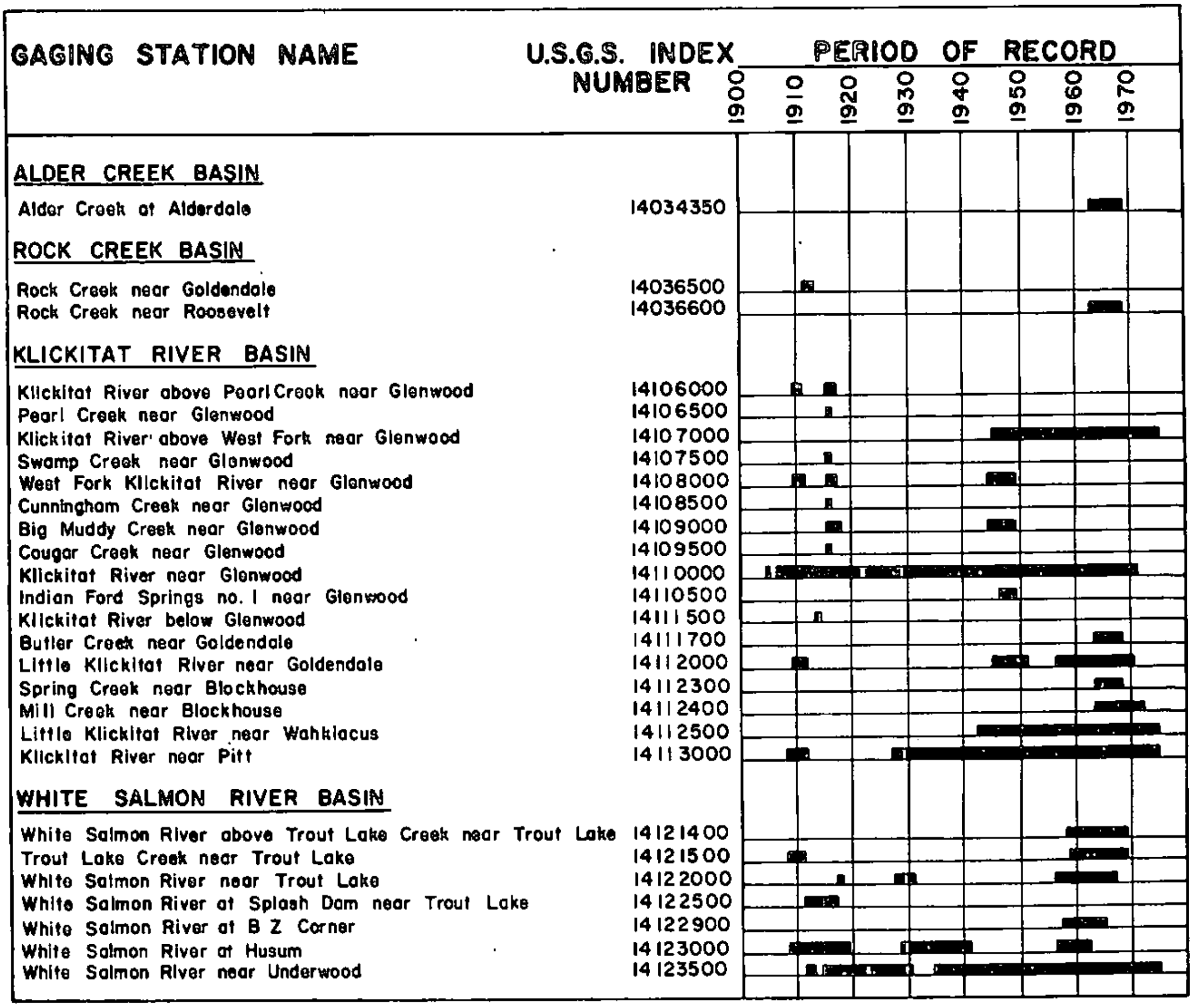

FIGURE 22. Bar chart of stream gaging station records, Klickitat County and upper Klickitat River basin, Washington.

River near Glenwood where measurements were begun in 1905 and discontinued in 1971. Gaging station records of the Klickitat River, near Pitt, and the White Salmon River, near Underwood, are also of considerable length.

Only three gaging stations have been operated in the eastern half of the county. The longest periods on record in this area are from 1963-1968 for stations on Alder Creek and Rock Creek. As these were the only stations with significant periods of record in the eastern part of the county, and because record periods overlap those of many stations in the western part, the six year interval, 1963-1968, is used for comparative purposes in this report.

While most of the gaging station records are short, the stations on the Klickitat River near Glenwood, and Klickitat River near Pitt, are of sufficient length to give an idea of long-term variations. Comparison of the average annual discharge at these stations with the moving precipitation averages from Goldendale furnish insight into the relationships between the quantities. Attempts to use records from these stations to generate synthetic discharge values for short record stations were not successful because of the extreme variation in stream character among basins.

Data Presentation

Basic stream gaging information was processed in a variety of ways and particular records were examined to analyze specific stream parameters. The limited period of record of many of the gaging stations resulted in only selected stations within the county and upper Klickitat basin being chosen for analysis. Choice of station was based on length of record, quality of record, and station location. The stations selected for analysis are listed in Table 2.

Data presented include a six-year mean daily discharge, maximum and minimum mean daily discharge, monthly maximum, minimum, and average discharge, discharge duration, and minimum discharge duration. A supplemental analysis of maximum discharge was made for selected gaging stations and is presented in the section on floods.

Most of the analyses are based on the entire usable period of record, but in the case of mean daily discharge, the selected six-year interval from

TABLE 2: Name and identification number of stream gaging stations selected for analysis, Klickitat County and upper Klickitat River basin, Washington.

Gaging Station	U.S.G.S. Location Number
White Salmon River near Trout Lake	14122000
White Salmon River near Underwood	14123500
Klickitat River above West Fork, near Glenwood	14107000
Klickitat River near Glenwood	14110000
Klickitat River near Pitt	14113000
Little Klickitat River near Goldendale	14112000
Little Klickitat River near Wahkaicus	14112500
Alder Creek at Alderdale	14034350
Rock Creek near Roosevelt	14036600

1963 to 1968 is used. Analysis of discharge duration is made for both the period of record and the six-year study period.

Six-Year Mean Daily Discharge

Mean daily discharge of each of the selected gaging stations is presented by means of a hydrograph -- a plot of discharge versus time -- which is useful in determining drainage basin characteristics, as the shape of an individual hydrograph reflects the nature of drainage basin parameters.

Because a hydrograph of a single year's discharge record may not be representative of the stream's normal characteristics, it is often useful to use a long-term hydrograph. To reduce the possibility of bias and to facilitate comparison among drainage basins within the county, a hydrograph of the six-year period 1963-1968 is presented for each station.

Maximum and Minimum Mean Daily Discharge

Hydrographs of the maximum and minimum mean daily discharge for the entire period of record have been prepared. These provide an estimate of the upper and lower limits of flow that might reasonably be expected. Longer stream gaging station records provide a more representative picture of the extremes.

Minimum, Maximum, and Average Monthly Discharge

In addition to daily minimums and maximums, monthly maximums, minimums and average discharges for each selected station are presented. Monthly data presentation is beneficial because the large time unit tends to smooth instantaneous discharge variations due to thunderstorms or minor freeze-ups and presents a more representative picture of the minimum, maximum, and average discharge that could be expected in any month.

Discharge Duration

Analysis of discharge duration (the percent of time that a given discharge was equaled or exceeded) is presented as a series of cumulative frequency curves. These curves are generally referred to as flow duration curves and are explained in detail by Searcy (1959). The curves provide a means of examining a stream's flow characteristics and, because of the nature of the curve, they are particularly useful in examining low flow characteristics. For the selected station within Klickitat County, two flow duration curves have been prepared, one of the six-year comparison period (1963-1968) and one for the entire period of record at each gaging station.

The flow duration curve is prepared by ranking mean daily discharge values according to their magnitude and determining the percent of time that a specified discharge was equaled or exceeded. Logarithmic discharge values normally are plotted on the ordinate versus a probability percentage distribution on the abscissa. A curve drawn through the plotted points represents the average condition for the period of record. Searcy (1959, p. 2) cautions that in the strictest sense the flow duration curve applies only to the period for which the data used to develop the curve are pertinent. He does allow, however, that if the streamflow during the period on which the flow duration curve is based represents the long-term flow of the stream, the curve may be considered a probability curve and used to estimate the percent of time that a specified discharge will be equaled or exceeded in the future.

Minimum Discharge Duration

An analysis of minimum streamflow, similar to flow duration, was also made. This low flow analysis was compiled by the U. S. Geological Survey in accordance with standards established by Riggs (1972). In the analysis, the lowest discharge occurring during the specified number of days at recurrence intervals varying from 1.01 to 100 years is determined. In most cases the 50- and 100-year low flows are a calculated projection based on the existing period of record.

Low flow analysis is useful because of the demand on surface-water resources during periods of low flow and for determining availability of water for impoundment and other hydraulic projects. Low flow analysis, like flow duration work, can be used in some cases to predict the probability of specified discharges in the future.

Discussion of Surface-Water Resources

Plates I and II (in pocket) outline the major drainage basins within Klickitat County and the principal streams within these basins. Plate III provides similar information for the upper Klickitat River basin in Yakima County. The location of stream gaging stations, as well as the location of miscellaneous discharge and crest-stage measurements, are indicated on these plates. Gaging station locations are shown in Figure 22. Miscellaneous and crest stage measurement locations are cross referenced to Tables A-1, A-2, A-3 in Appendix A. Miscellaneous measurement locations do not have an identification number and thus a simple consecutive numbering system is used in this report.

Because of the wide diversity in stream and drainage basin characteristics, surface-water resources are best discussed by individual drainage basin. For purposes of comparison, Table 3 summarizes pertinent information from principal gaging stations in the major drainage basins of the county. The summary includes drainage area, period of record, mean discharge for the period of record, and the dates and discharges of the instantaneous maximums and minimums.

Alder Creek Basin

Alder Creek drains an area of about 200 square miles in southeast Klickitat County (Plate II). The area drained extends from near Bickleton, in the northwestern part of the basin, to the extreme southeast corner of the county. Generally, Alder Creek and its principal tributaries, Six Prong Creek and Spring Canyon Creek, drain almost due south to the north side of Columbia Hills and Alder Ridge. From there, the creek courses eastward along the axis of the syncline (Plate V) to where it breaches the Alder Ridge-Columbia Hills anticline near the southeast corner of the county and discharges into the Columbia River.

TABLE 3. General information from selected stream gaging stations, Klickitat County and upper Klickitat River basin, Washington.

Station No. (USGS)	Station Name	Location	Drainage Area (Mi^2)	Period of Record
14034350	Alder Creek at Alderdale	NE4, SW4, Sec. 10, T. 4 N., R. 23 E., on left bank, 1 mile upstream from mouth.	197.0	1963-1968
14036600	Rock Creek near Roosevelt	W2, NE4, Sec. 16, T. 3 N., R. 19 E., on left bank on down-stream side of coun-ty road bridge.	213.0	1963-1968
14107000	Klickitat River above West Fork near Glenwood	NW4, SW4, Sec. 18, T. 9 N. R. 13 E., on right bank, 17 miles, north of Glenwood.	151.0	1944-1975
14108000	West Fork Klickitat River near Glenwood	SE4, Sec. 14, T. 9 N., R. 12 E., on right bank at road bridge, 2 miles upstream from mouth.	89.0	1910, 1916, 1944-1948
14110000	Klickitat River near Glenwood	SE4, Sec. 14, T. 7 N., R. 12 E., on left bank, 5.2 miles north of Glenwood.	360.0	1905, 1907, 1908, 1909-1971
14112000	Little Klick-itat River near Golden-dale	NE4, SW4, Sec. 10, T. 4 N., R. 16 E., on right bank, 400 ft. upstream from Highway 97 bridge.	83.5	1910-1912 1946-1951, 1957-1970
14112400	Mill Creek near Block-house	NW4, SW4, Sec. 5, T. 4 N., R. 15 E., on left bank, 1.9 miles northwest of Block-house	26.9	1966-1972
14112500	Little Klick-itat River near Wahkai-cus	SW4, SE4, Sec. 9, T. 4 N., R. 14 E., on right bank, 450 ft. upstream from State Highway 142 bridge.	280.0	1944-1975
14113000	Klickitat River near Pitt	SW4, Sec. 8, T. 3N. R. 13 E., on left bank, 2.8 miles south of Pitt.	1297.0	1909-1912, 1928-1975

Mean Discharge for Period of Record (cfs)	Minimum (cfs)		Maximum (cfs)	Date	Basin Runoff cfs/Mi2
8.51	0.20	July 25, 1963 June 26-July 11, 1968 July 28-July 30, 1965	17,600	Dec. 22, 1964	0.04
45.80	0.0	Many days	14,200	Dec. 22, 1964	0.22
336.00	4.4	Feb. 1, 1954	3,280	May 27, 1948	2.23
304.00	148.0	Oct. 17-Oct. 19, 1945	1,560	May 26, 1948	3.42
841.00	204.0	Nov. 28, 1931	9,870	Dec. 22, 1933	2.34
60.10	0.0	Aug. 21, 1967 Sept. 4, 5, 1967	5,200	Dec. 22, 1964	0.72
15.80	0.1	Aug. 14, 16, 18, 23, 24, 25, 1965	290	Dec. 23, 1964	0.59
182.00	9.7	Sept. 7, 8, 1973	17,500	Jan. 15, 1974	0.65
1630.00	445.0	Dec. 17, 1964	47,400	Jan. 15, 1974	1.26

TABLE 3 (Cont'd)

Station No. (USGS)	Station Name	Location	Drainage Area (Mi^2)	Period of Record
14121400	White Salmon River above Trout Lake Creek near Trout Lake	SE4, SE4, Sec. 3, T. 6 N., R. 10 E., on right bank, 2.2 miles north of Trout Lake.	64.9	1959-1969
14121500	Trout Lake Creek near Trout Lake	SE4, SW4, Sec. 15, T. 6 N., R. 10 E., on right bank, 0.4 miles downstream from Trout Lake.	69.3	1909-1911, 1959-1969
14122000	White Salmon River near Trout Lake	NW4, SE4, Sec. 24, T. 6 N., R. 10 E, on left bank, 1.7 miles south-east of Trout Lake.	185.0	1918, 1928-1931, 1957-1967
14122500	White Salmon River at Splash Dam near Trout Lake	E2, Sec. 6, T. 5 N., R. 11 E., on right bank at Splash Dam, 5 miles southeast of Trout Lake.	240.0	1912-1917
14122900	White Salmon River at B-Z Corner	NW4, SW4, Sec. 1., T. 4 N., R. 10 E., on left bank, 0.8 miles north of B-Z Corner.	269.0	1958-1965
14123000	White Salmon River at Husum	SW4, SW4, Sec. 30, T. 4 N., R. 11 E., on right bank at Husum.	294.0	1909-1919, 1929-1941, 1957-1962
14123500	White Salmon River near Underwood	NW4, NW4, Sec. 14, T. 3 N., R. 10 E., on right bank, 1000 ft. downstream from Pacific Power & Light Co.'s Conduit Power Plant.	386.0	1912-1913, 1915-1930, 1935-1975

Mean Discharge for Period of Record (cfs)	Minimum (cfs)		Maximum (cfs)	Date	Basin Runoff cfs/Mi^2
237.00	98.0	Mar. 4, 1966	1,080	Dec. 23, 1964	3.65
264.00	26.0	Sept. 12, 13, 1963	2,900	Dec. 23, 1964	3.81
382.00	35.0	Aug. 26, 1931	3,860	Nov. 20, 1962	2.06
443.00	52.0	Aug. 1, 4-6, 1915	2,160	Apr. 3, 1915	1.85
791.00	287.0	Oct. 4, 5, 1963	3,830	Nov. 20, 1962	2.94
980.00	340.0	Dec. 30, 1930	10,800	Dec. 22, 1933	3.33
1140.00	158.0	Jan. 17, 1950	15,300	Jan. 15, 1974	2.95

One gaging station was operated near the mouth of Alder Creek from 1963-1968. No diversions existed above the gaging station, and aside from general stock watering, there has been little use. Most of the area within the basin is not irrigated so there is little contribution to the natural flow from irrigation return flow.

Field observation and conversation with area residents indicate that all streams within the basin are intermittent, flowing only during periods of snowmelt or heavy precipitation. The six-year and maximum-minimum hydrographs (Figures 23 and 24) prepared from gaging station data, however, indicate flow is sustained through the year, because flow was measured

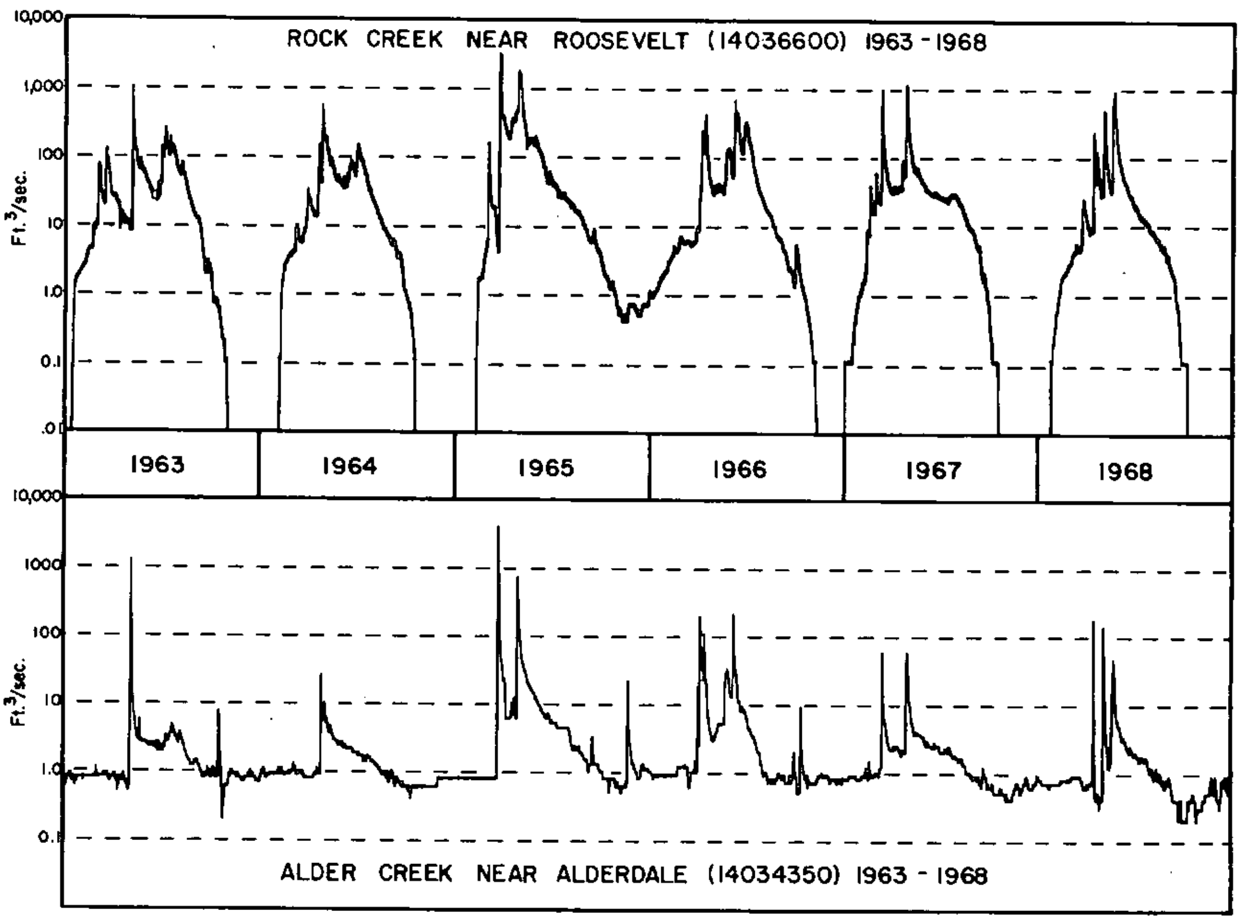

FIGURE 23. Mean daily discharge for Rock Creek and Alder Creek, Klickitat County, Washington.

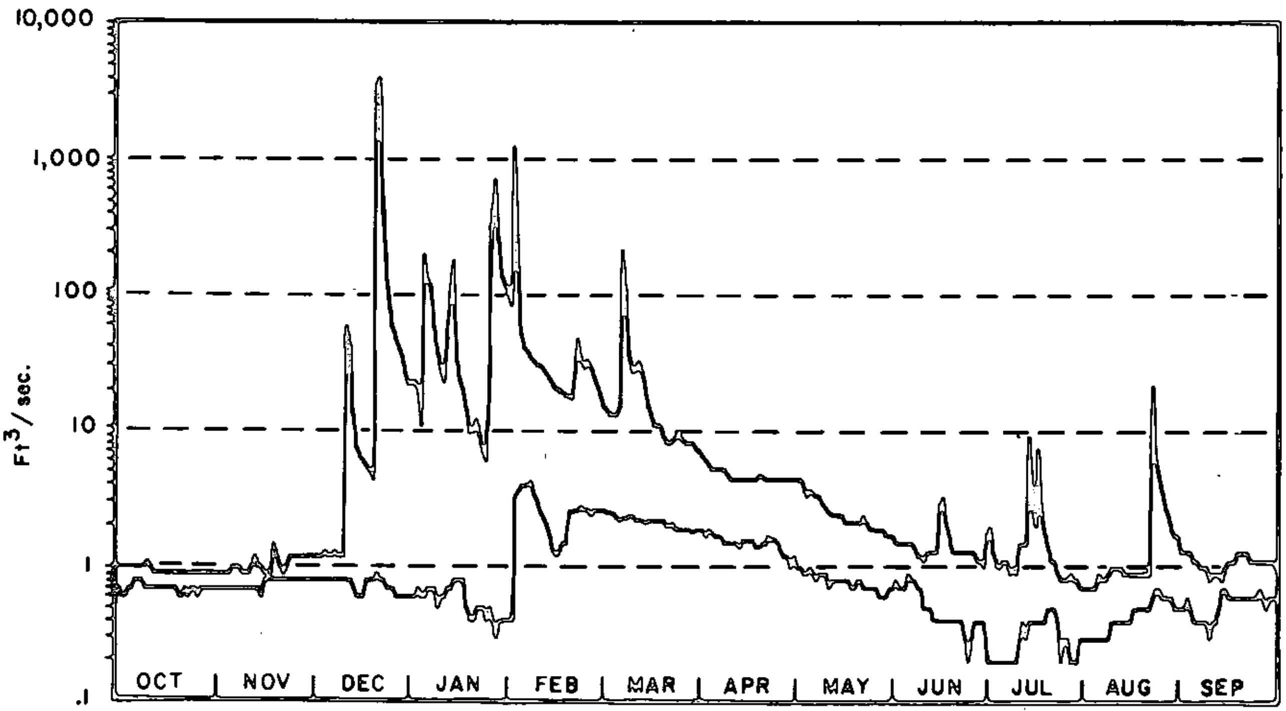

FIGURE 24. Maximum-minimum discharge (1963-1968), Alder Creek at Alderdale Washington.

immediately downstream from a perennial spring (5/23-34Q1s) in Alder Creek canyon. The spring provides a relatively constant discharge of about 0.8 cfs which can be used as an approximate baseline in interpreting the hydrographs.

The hydrographs indicate the "flashy" nature of the streams in eastern Klickitat County. The very steeply rising limb on both of the six-year and maximum hydrographs indicate rapid concentration of direct runoff from high-intensity precipitation. Recession flows are similarly steep, indicating immediate runoff with relatively little contribution from bank storage. Also indicative of rapid runoff is the wide variation in discharge during a year. Figure 25 shows the monthly maximum discharge to be 8500 cfs for December, in contrast to a discharge of near 0 for May through November. The discharge variation is further evidenced by the flow duration curves (Figure 26) which indicate widely varying discharges occurring 30 percent of the time. The near horizontality at the lower end of the flow duration curve is in response to the sustained flow from the nearby spring.

Alder Creek Basin can be considered typical of many drainage basins in arid and semiarid areas. The areas normally have steep gradients and sparse vegetation which results in rapid runoff from precipitation. Streams in these areas are normally intermittent, but when flowing, often exhibit high flows over several orders of magnitude. The intermittent nature of the streams and the very rapid runoff suggest little contribution from basin storage in these areas.

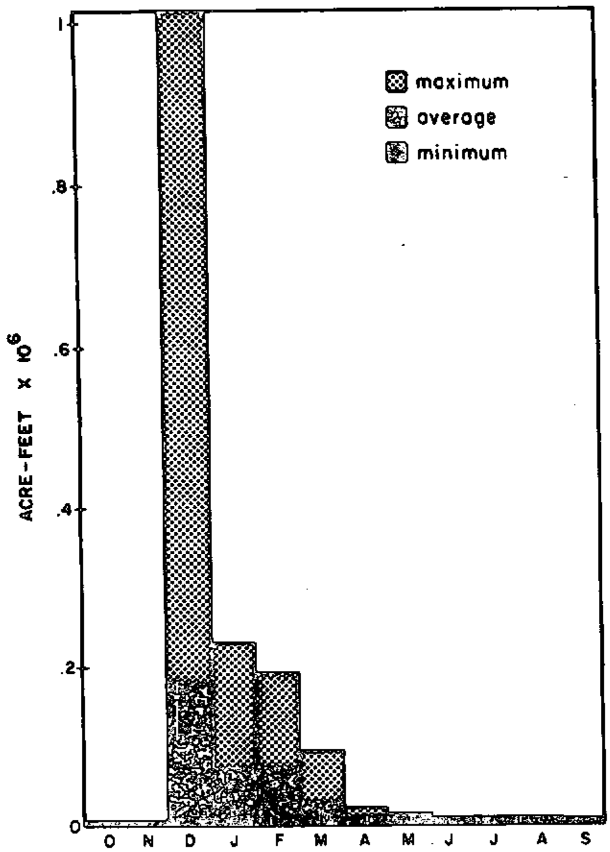

FIGURE 25. Maximum, minimum and average monthly discharge, 1963-1968, Alder Creek at Alderdale, Washington.

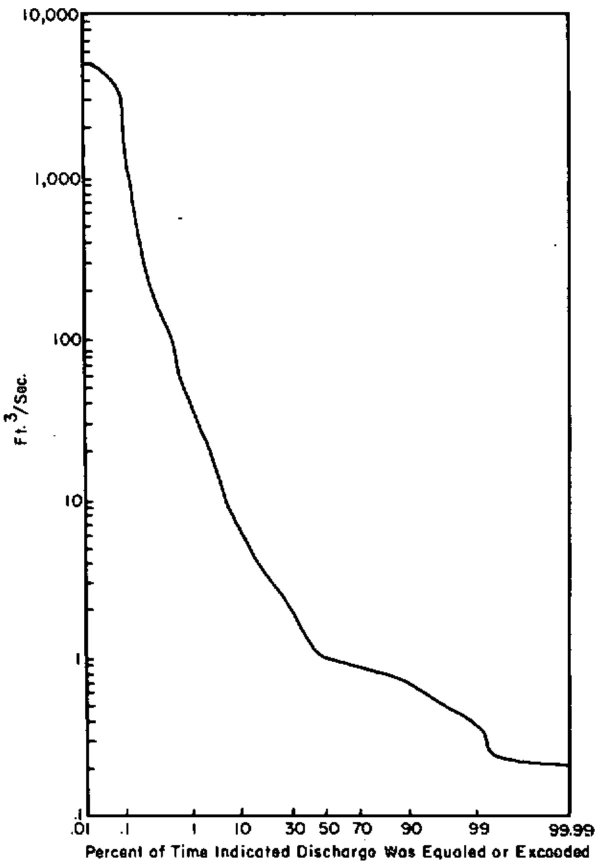

FIGURE 26. Flow duration, 1963-1968, Alder Creek at Alderdale, Washington.

Surface-water Resources

Rock Creek Basin

The Rock Creek basin occupies an area of slightly more than 200 square miles. It is situated in the east-central part of the county and forms a large circular basin with a well-developed dendritic drainage pattern. The basin drains an area extending from the Horse Heaven Hills to the Columbia River. It is bounded by Luna Butte on the west and an indefinite topographic divide between tributaries of Harrison and Squaw Creek and Wood Gulch on the east (Plate II). Mean annual precipitation within the basin varies between 15 and 25 inches, with the greater amount falling in the northern and western areas of the basin.

Two gaging stations have operated in the Rock Creek basin (Figure 22). The station near Goldendale was operated for a year and a half in 1912 and 1913. The gaging station near Roosevelt (see Plate II), located near the mouth of Rock Creek, was operated for the six-year period 1963-1968. No major diversions or withdrawals are made above the gaging station.

Mean annual precipitation is greater in Rock Creek basin than in Alder Creek basin. This produces differences in runoff which can be easily recognized by comparing hydrologic data from the two basins. Rock Creek basin has only a slightly larger area than Alder Creek basin. However, for the same period of record, the average discharge of Rock Creek was more than five times that of Alder Creek (Table 3). Nevertheless, the instantaneous maximum discharge, which occurred on the same day for each station, was 3400 cfs less for Rock Creek than Alder Creek. This comparison suggests that, although the Rock Creek basin receives more precipitation, a smaller percentage of it occurs as direct runoff than in the Alder Creek basin. Apparently, bank storage is a more significant contributor to the flow of Rock Creek.

Comparison of six-year and maximum-minimum hydrographs for the two stations reflect the differences between the two basins. The rising limbs on both hydrographs of Rock Creek, though steep, are not as abrupt as those of Alder Creek. Similarly, the recession limbs are more gradual. In general, runoff in Rock Creek basin appears less direct and instantaneous than in Alder Creek basin.

Comparison of flow duration curves for the two stations (Figures 26 and 28) indicates that maximum discharges are of the same order of magnitude. Flow in Rock Creek, however, is sustained at a much higher level for 70 percent of the time than is that of Alder Creek. This relationship is also apparent in the hydrographs of monthly maximum and average discharge at the two stations (Figures 25 and 29).

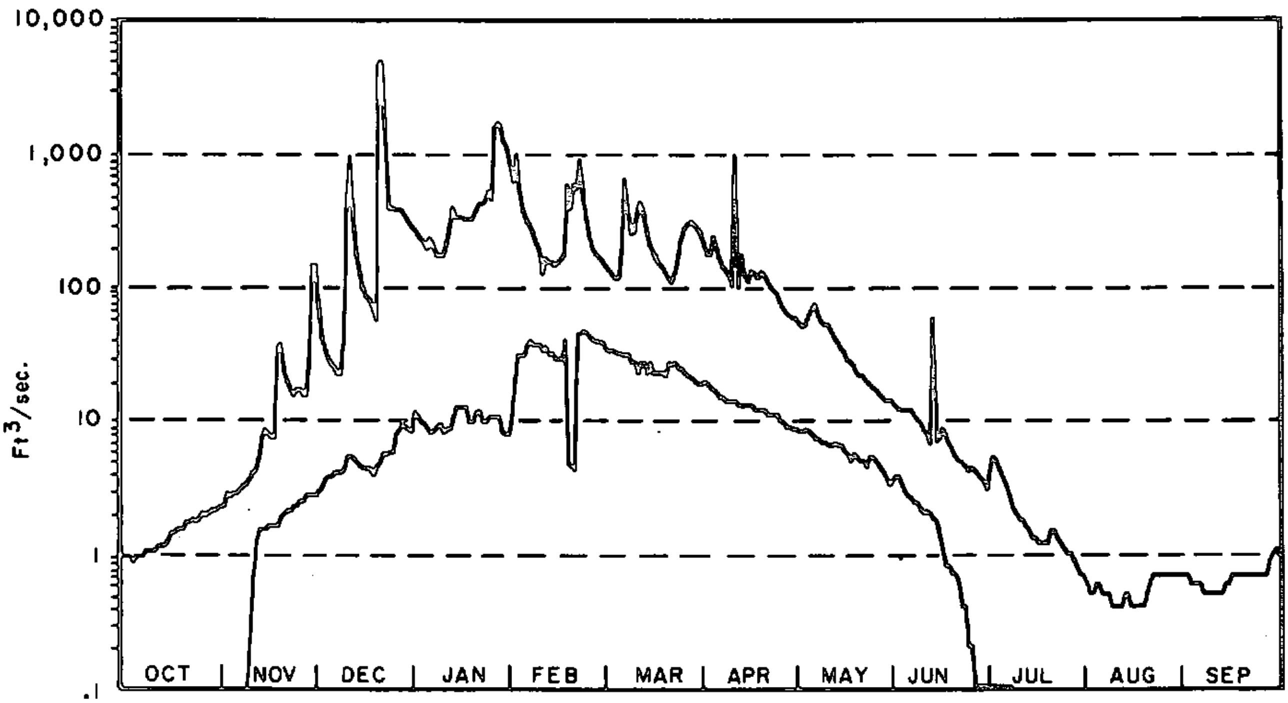

FIGURE 27. Maximum-minimum discharge (1963-1968), Rock Creek near Roosevelt, Washington.

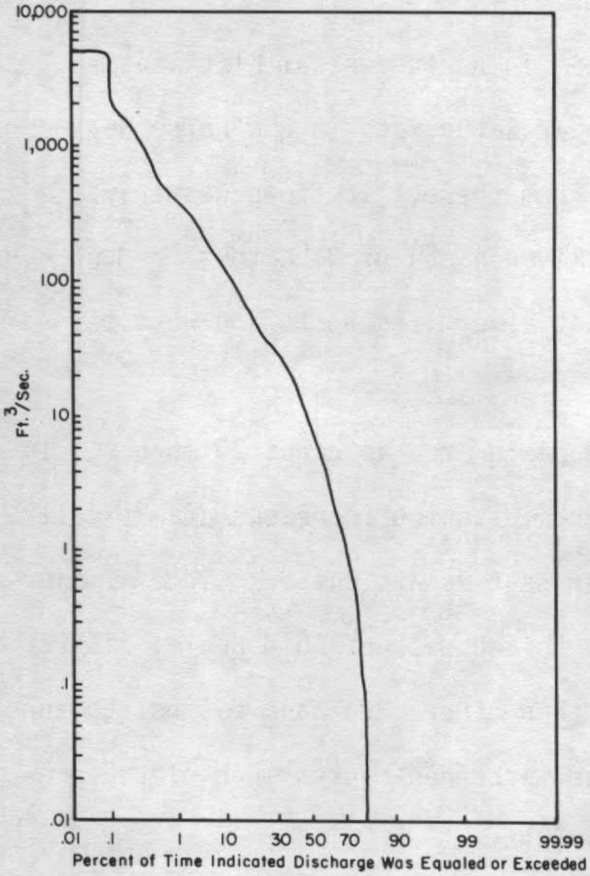

FIGURE 28. Flow duration, 1963-1968, Rock Creek near Roosevelt, Washington.

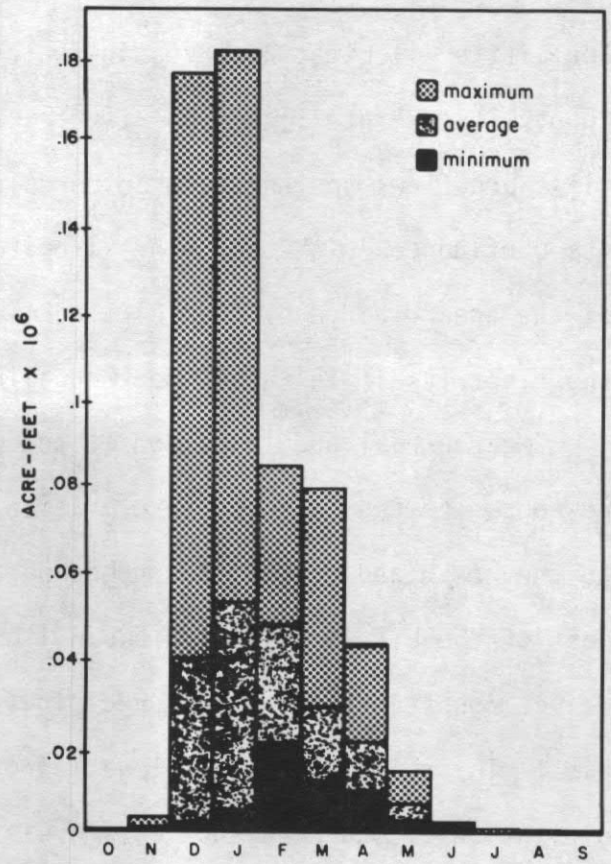

FIGURE 29. Maximum, minimum, and average monthly discharge, 1963-1968, Rock Creek near Roosevelt, Washington.

Klickitat River Basin

The Klickitat River basin is the largest drainage basin in Klickitat County, having an area of over 1300 square miles. This basin includes approximately 400 square miles in western Yakima County as well as most of central Klickitat County, including subsidiary drainage basins of Little Klickitat River and Swale Creek. In the following discussion the Little Klickitat River and upper Klickitat River basins are discussed separately.

Little Klickitat River Basin

The Little Klickitat River basin is located in north-central Klickitat County (see Plate I). The river rises near Satus Pass in the Horse Heaven Hills and flows southwest to Goldendale. From there, it flows westerly to its confluence with the main Klickitat River north of Wahkaicus. Most of the area drained by the Little Klickitat River lies north and west of the river itself in the Simcoe Mountains.

Mean annual precipitation in the Goldendale area is about 20 inches. In response to the increase in elevation, precipitation increases dramatically to the north and reaches 35 inches per year near Potato Butte. Since a major part of the Little Klickitat basin lies north and west of Goldendale, it receives substantially more precipitation than other drainage basins to the east. The relatively high elevation of the watershed causes much of the precipitation to occur as snow during winter months.

Two principal gaging stations have been operated on the Little Klickitat River. One station, just north of Goldendale, was maintained intermittently and the other is still operated near the mouth of the Little Klickitat River, just north of Wahkaicus (see Plate I). In addition, several short-term stations have been established on tributaries to the Little Klickitat River (see Figure 18). The station near Goldendale began operation in 1910 but was maintained for only one year. The station subsequently operated intermittently from 1947-1970. The station near Wahkaicus has been operated continuously since 1947. No major diversions exist on the Little Klickitat River; however, at numerous locations along its course water is withdrawn for irrigation purposes. Unregulated discharge into the Little Klickitat River from the Goldendale sewage treatment plant is estimated to be about 2 cfs.

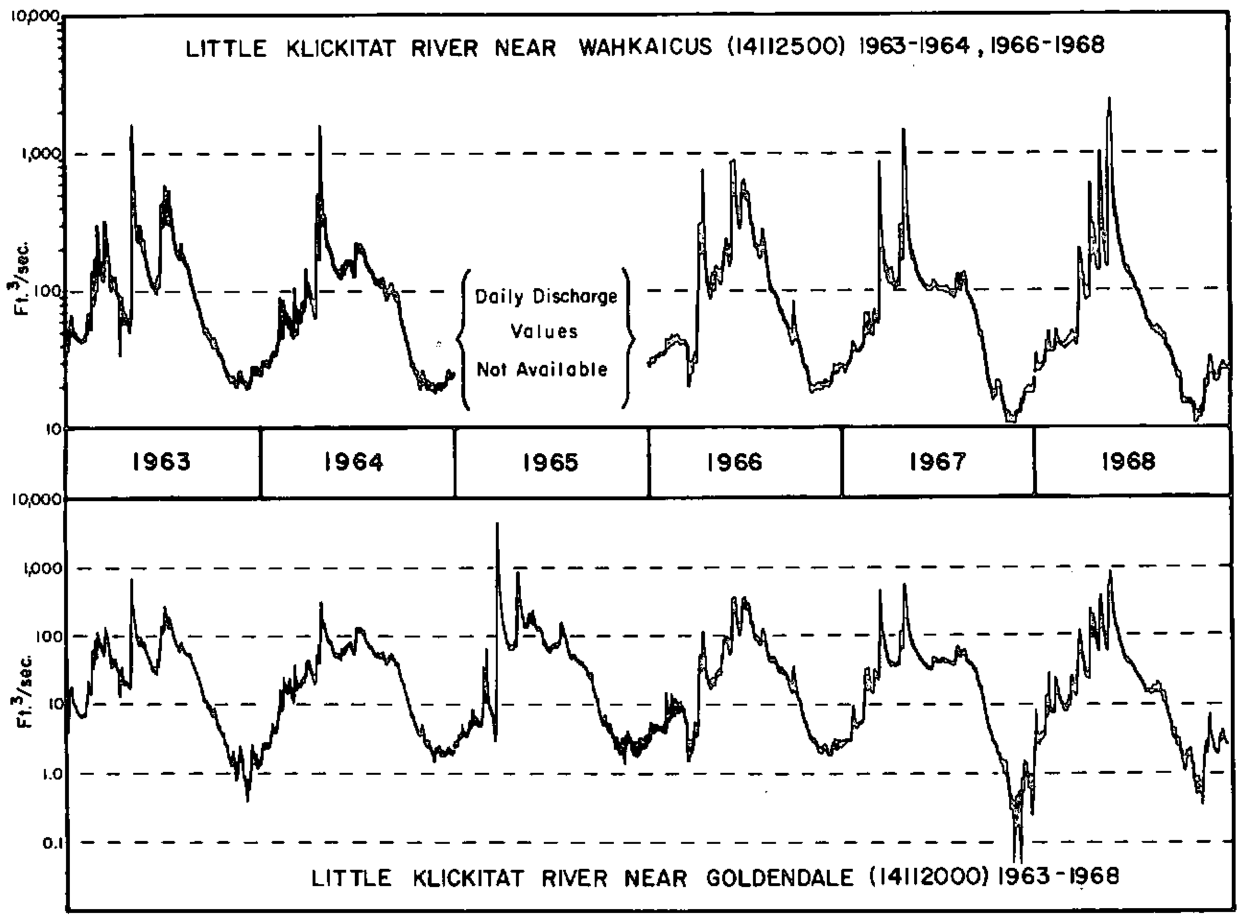

FIGURE 30. Mean daily discharge, Little Klickitat River, Klickitat County, Washington.

Comparison of hydrologic data for the Little Klickitat River basin with the Rock Creek and Alder Creek basins reveals the result of increased precipitation within the Little Klickitat basin. The gaging station at Goldendale, although measuring discharge from a drainage area less than half as large as the Rock Creek station, shows an average discharge which exceeds that of Rock Creek by 15 cfs (Table 3). Similarly, basin runoff of the Little Klickitat River near Goldendale is more than three times that of Rock Creek. A decrease in basin runoff contribution is evident between the gaging stations near Goldendale and Wahkaicus. This difference occurs because the station

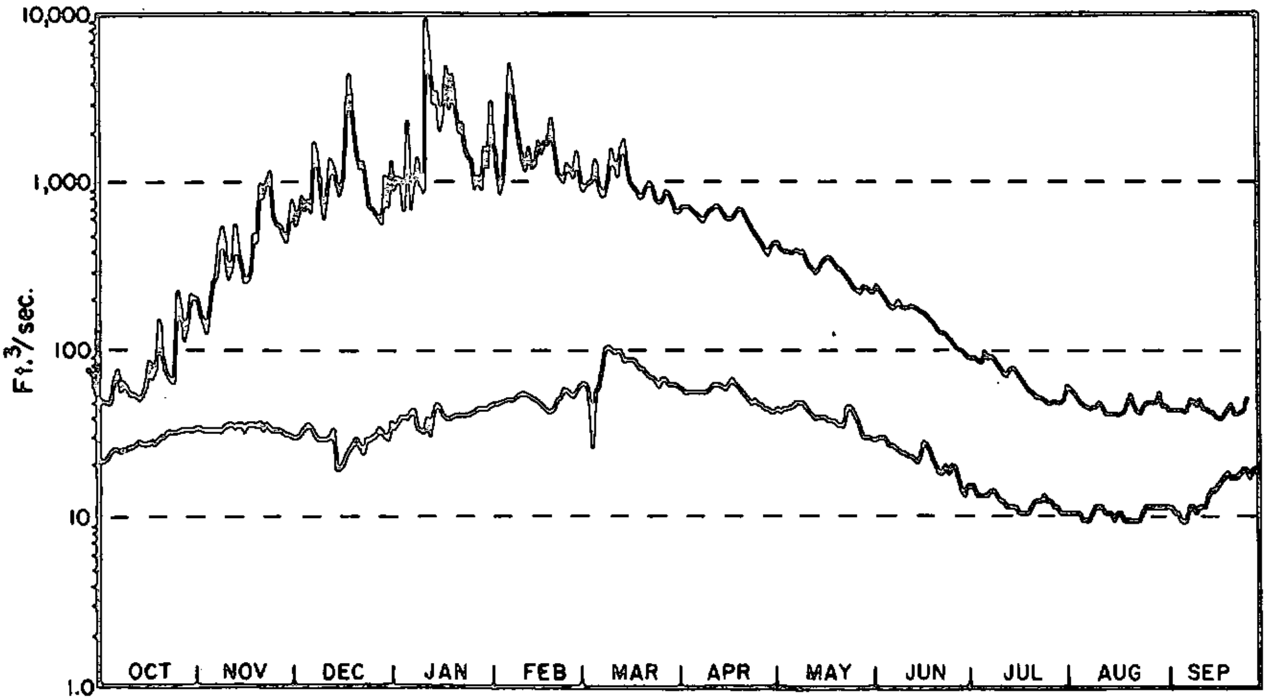

FIGURE 31. Maximum-minimum discharge, 1950-1975, Little Klickitat River near Wahkaicus, Washington.

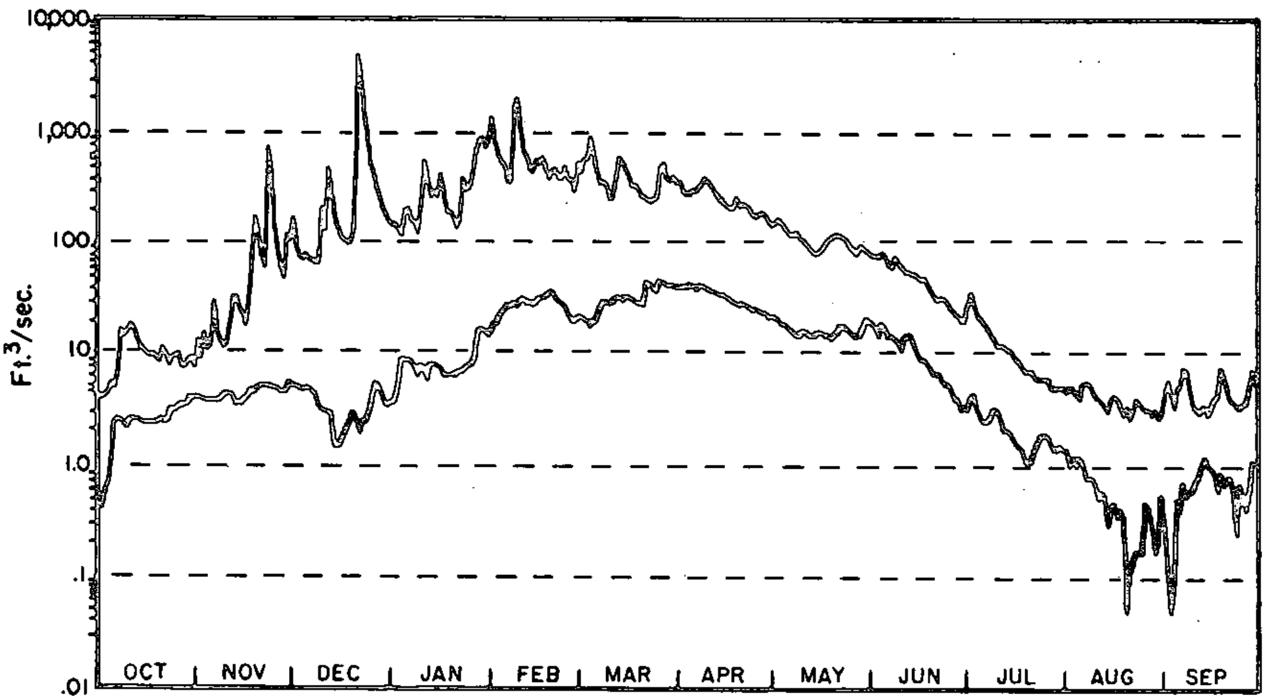

FIGURE 32. Maximum-minimum discharge, 1958-1970, Little Klickitat River near Goldendale, Washington.

near Goldendale gages the upper watershed where precipitation is relatively high, while the station near Wahkaicus includes contributions from the southern part of the drainage basin where precipitation is much lower.

Comparison of flow duration curves for the two stations on the Little Klickitat River (Figures 33 and 34), also reflects the differences in watershed. Although minimum discharges at both stations are of the same order of magnitude, the slope of these curves at the lower ranges of flow are considerably different. Much of the difference may be attributed to contributions from Mill Creek which maintains a relatively constant discharge of about 15 cfs the year-round because of its springfed sources.

Upper Klickitat River Basin: Much of the Klickitat River's discharge is derived from its upper watershed located in western Yakima County. This basin (see Plate III) has an area of about 400 square miles and is located on the rugged eastern slope of the Cascade Mountains. Mean annual precipitation is highest on the slopes of Mt. Adams, often in excess of 100 inches.

Information is available from two stream gaging stations in the upper Klickitat River basin (Figure 22). One station is located above the confluence of the Klickitat River and its west fork. The other was operated for 62 years on the Klickitat River just north of the Yakima-Klickitat County line (see Plate III). There is no diversion above the station near West Fork; however, diversion of tributaries into the Klickitat River above the lower station is effected via Hellroaring Ditch. Water is normally diverted from June until the end of October and is estimated to total between 10,000 and 20,000 acre-feet per year (Cline, 1976).

Six-year hydrographs for the two gaging stations in the upper Klickitat basin are unusually similar (Figure 37). This similarity relates to the fact

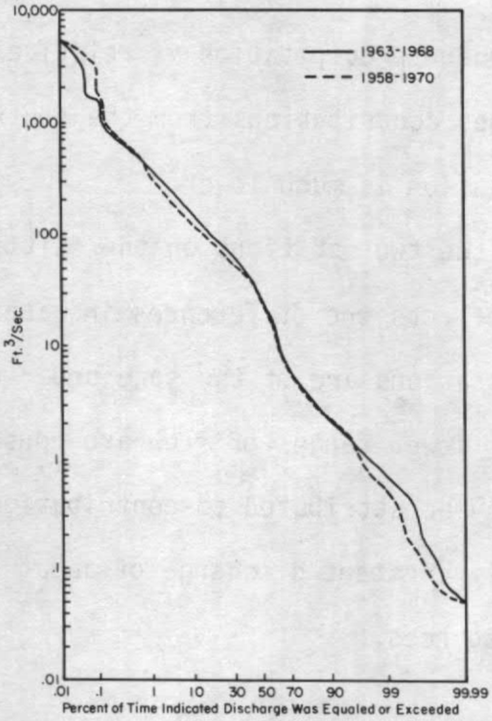

FIGURE 33. Flow duration, Little Klickitat River near Goldendale, Washington.

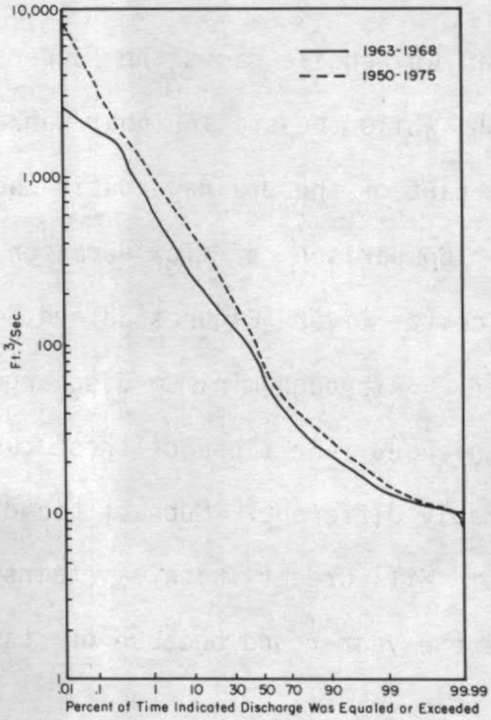

FIGURE 34. Flow duration, Little Klickitat River near Wahkaicus, Washington.

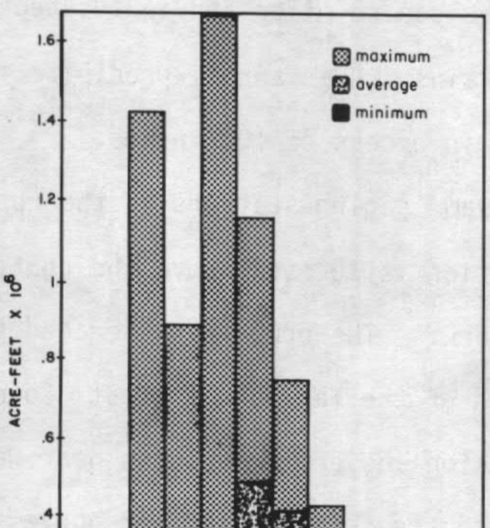

FIGURE 35. Maximum, minimum and average monthly discharge, 1958-1970, Little Klickitat River near Goldendale, Washington.

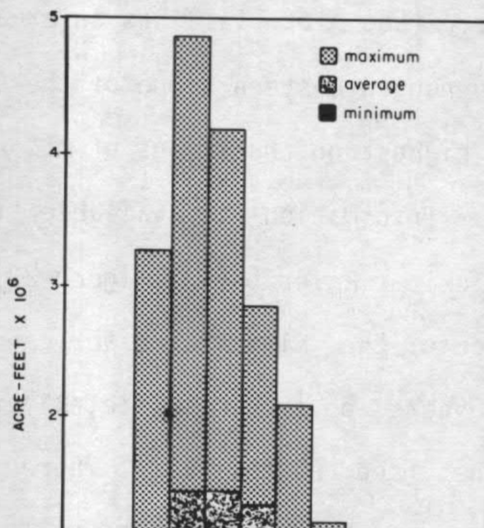

FIGURE 36. Maximum, minimum, and average monthly discharge, 1950-1975, Little Klickitat River near Wahkaicus, Washington.

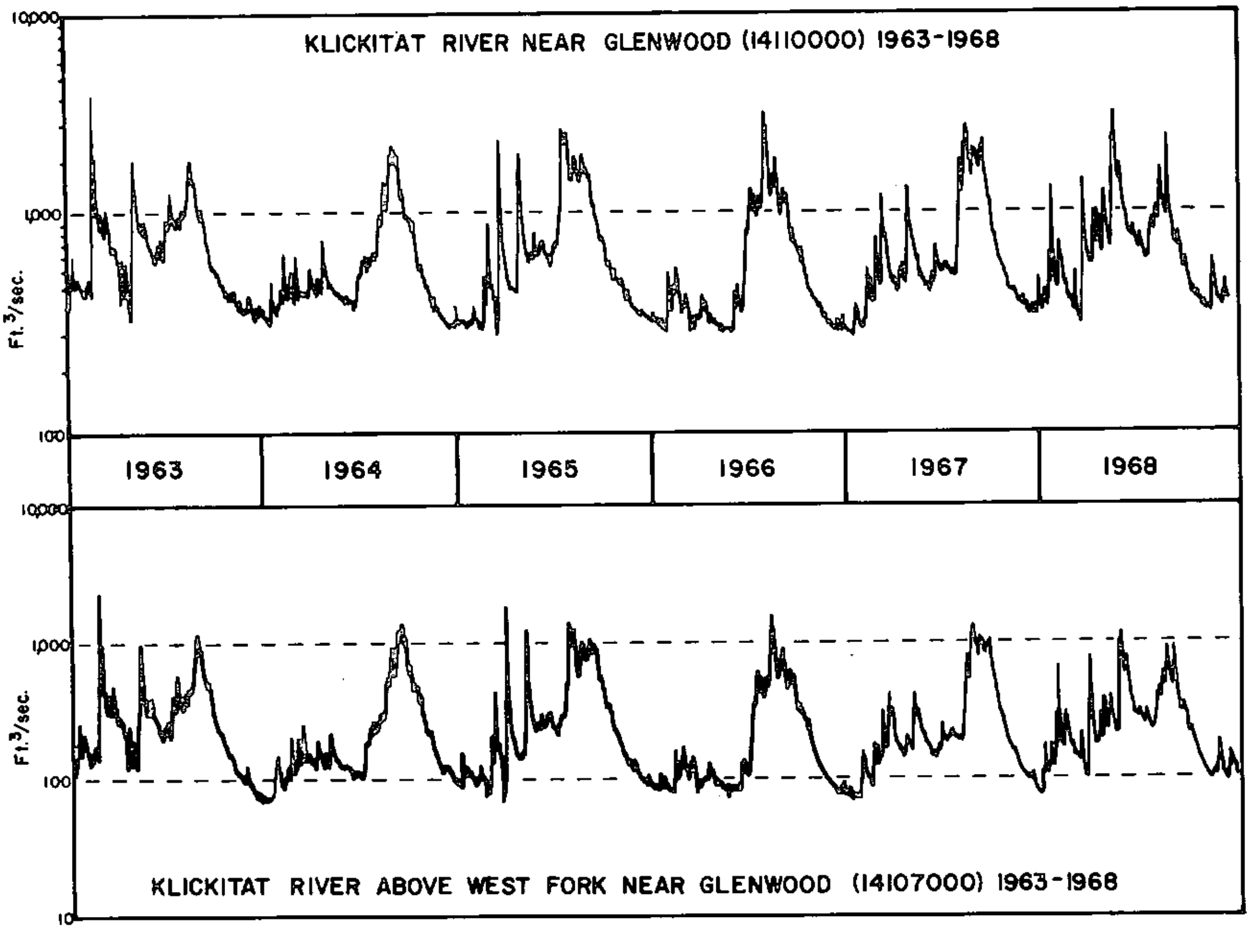

FIGURE 37. Mean daily discharge, upper Klickitat River basin, Washington.

that the stations are only 12 miles apart and that the upper basin has a general geographic uniformity. The hydrographs show little variation between high and low flows compared to hydrographs for streams to the east, and indicate that relatively high flows are maintained during dry summer months.

Maximum-minimum hydrographs (Figures 38 and 39) also illustrate the limited discharge range and reflect the contribution of ice and snowmelt to the river. The contribution of snowmelt can be seen in the bimodal appearance of the maximum hydrograph for the station near Glenwood and in the high minimum flows occurring in late spring on both hydrographs. Snowpack meltwater makes up a large percentage of the annual discharge and is responsible for

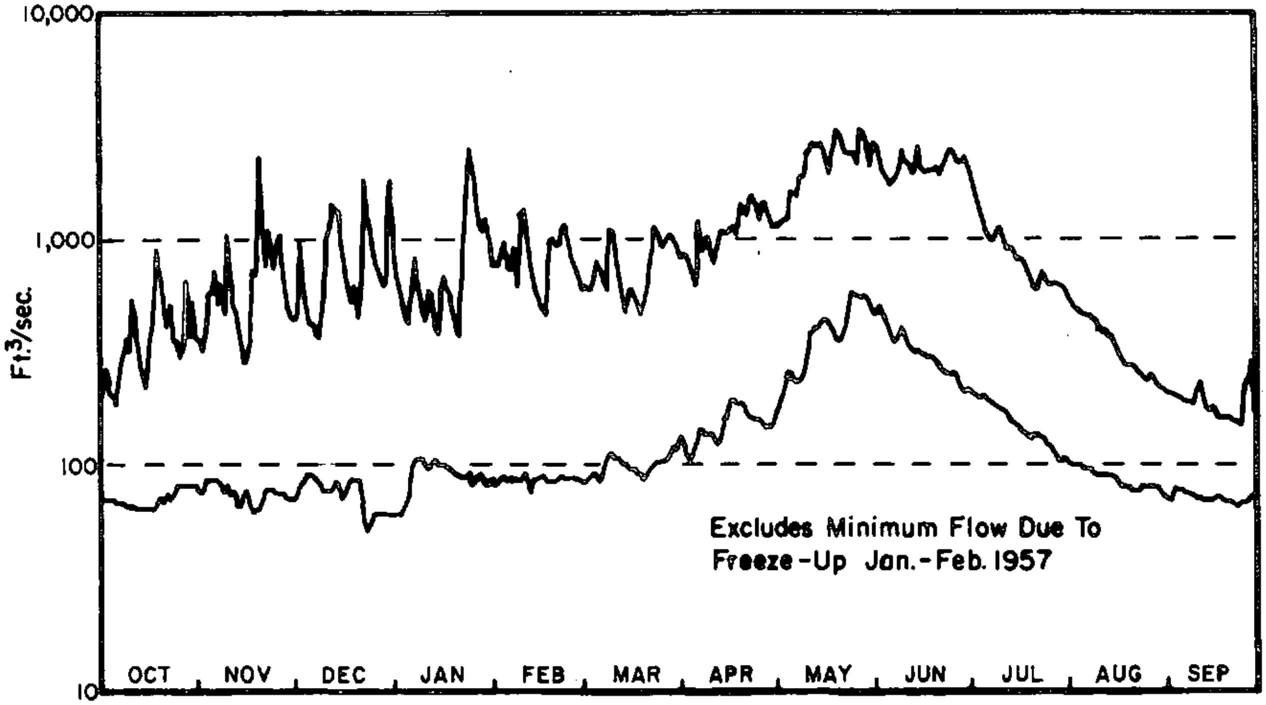

FIGURE 38. Maximum-minimum discharge, 1945-1975, Klickitat River above West Fork, near Glenwood, Washington.

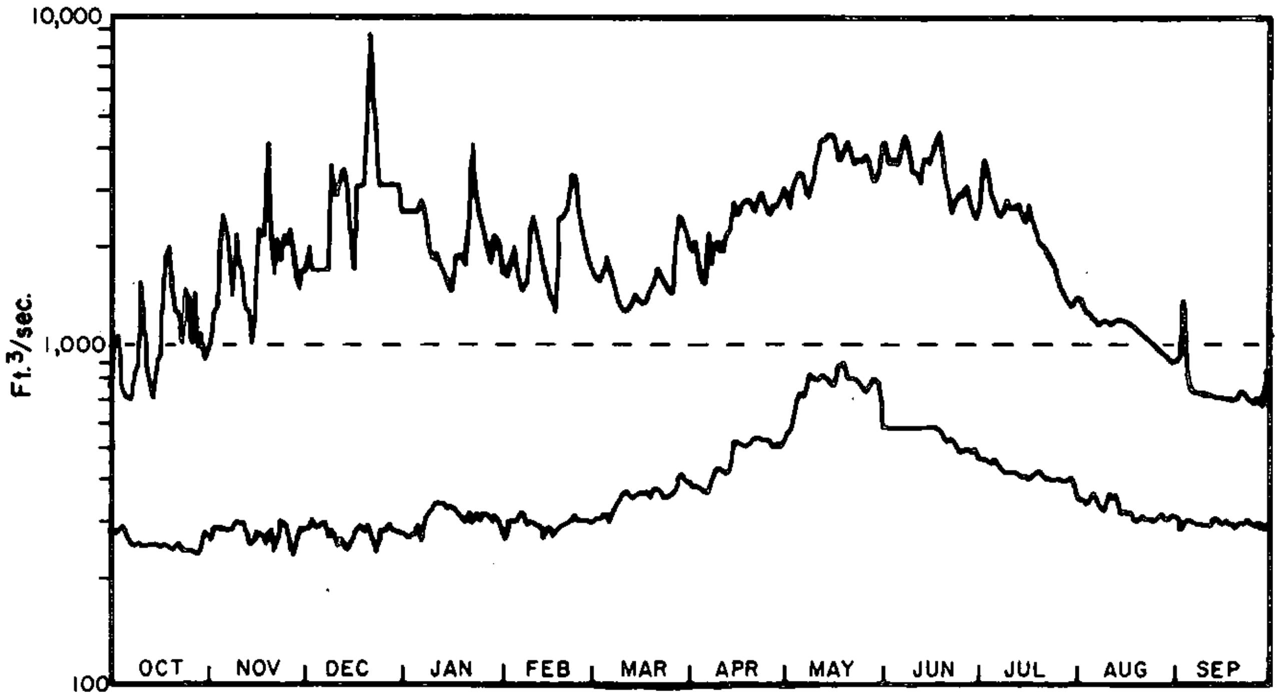

FIGURE 39. Maximum-minimum discharge, 1912-1971, Klickitat River near Glenwood, Washington.

the high sustained flow during precipitation-deficient months. The contribution from snowmelt is also evident in the monthly discharge data presented in Figures 40 and 41.

Like the stream hydrographs, the flow duration curves are very similar for both gaging stations (Figures 42 and 43), the main difference being the higher discharge at the lower station. Curves for both stations are relatively flat in their high frequency segments, which indicates good sustained flow during low-flow months. The sustained low flow is further substantiated by examination of Table 4. Analyses for both Klickitat River stations show relatively high flows, even at the projected 100-year recurrence interval. Comparison of low flow discharges in the upper Klickitat River with those of the Little Klickitat River indicate there is much less fluctuation in upper basin discharge, an apparent result of the relatively constant ice and snowmelt contribution.

Summary of Klickitat River Basin

In addition to the upper Klickitat and Little Klickitat drainage areas, the Klickitat River receives contributions from Outlet Creek, which drains the Camas Prairie-Glenwood area, Swale Creek, which drains the southern portion of the Goldendale-Centerville area, and numerous smaller drainages. Integration of all the subbasins results in a total drainage area for the Klickitat River in excess of 1300 square miles. As evidenced in the preceding section, the Klickitat Basin exhibits considerable diversity in precipitation and other basin parameters.

In addition to the stream gaging stations on the Little Klickitat and upper Klickitat Rivers, a gaging station has been operated on the main stem near Pitt, south of the town of Klickitat and about 10 miles upstream from

TABLE 4: Low-flow discharge at selected gaging stations, Klickitat County and upper Klickitat River basin, Washington*

Gaging Station: Location and U.S.G.S. Identification Number	Period of Record	Number of Consecutive Days	1.01	1.02	1.04
Klickitat River near Pitt (14113000)	1911-1915	7	938.97	903.44	865.16
		14	955.23	920.15	882.05
		30	972.30	939.36	902.90
		60	1015.21	980.70	942.47
		90	1070.96	1031.76	988.65
		120	1133.93	1091.66	1045.00
		183	1538.00	1443.00	1344.67
Klickitat River near Glenwood (1410000)	1911-1971	7	487.21	471.81	454.70
		14	495.28	480.79	464.46
		30	523.76	506.30	487.02
		60	580.60	555.69	529.19
		90	621.49	593.44	563.67
		120	686.09	652.79	617.44
		183	894.05	830.83	766.92
Klickitat River above West Fork near Glenwood (14107000)	1946-1975	7			
		14			
		30	138.82	133.09	126.88
		60	155.36	148.47	141.08
		90	180.05	170.81	160.28
		120	218.25	202.96	187.54
		183	301.52	176.78	252.15
Little Klickitat River near Goldendale (14112000)	1912, 1948-1951, 1959-1970	7	2.89	2.81	2.69
		14	3.21	3.10	2.95
		30	3.56	3.42	3.23
		60	4.62	4.34	4.02
		90	6.53	5.88	5.23
		120	10.62	8.89	7.40
		183	33.96	26.76	20.93
Little Klickitat River near Wahkaicus (14112500)	1946-1976	7	47.12	43.74	40.11
		14	47.68	44.28	40.64
		30	50.88	47.00	42.91
		60	51.11	47.75	44.13
		90	52.58	49.47	46.07
		120	57.81	54.14	50.22
		183	80.94	74.84	68.61
White Salmon River near Underwood (14123500)	1916-1975	7	784.18	751.60	716.76
		14	803.57	771.25	736.45
		30	836.43	804.72	770.00
		60	872.03	837.63	800.31
		90	922.16	882.27	839.50
		120	991.94	944.48	894.21
		183	1224.89	1153.65	1079.54

*Based on climatic year, April 1 - March 31.

1.11	1.25	2.00	5.00	10.00	20.00	50.00	100.00
808.35	757.72	667.73	586.34	547.04	516.20	483.16	462.10
824.95	773.50	680.82	595.71	554.21	521.48	486.27	463.76
847.13	795.78	700.68	610.65	565.91	530.28	491.66	466.81
883.77	829.45	728.36	632.19	584.30	546.13	504.75	478.13
923.06	863.01	752.77	649.61	598.81	558.57	515.21	487.46
973.65	908.03	786.97	673.26	617.23	572.90	525.18	494.70
1206.26	1090.19	900.02	744.81	675.29	623.10	569.57	536.47
428.36	403.89	358.08	314.11	292.05	274.38	255.12	242.68
438.81	414.50	367.81	321.76	298.28	279.31	258.52	245.02
457.53	430.36	380.01	332.26	308.49	289.54	268.97	255.73
490.49	456.65	297.95	346.43	322.08	303.19	283.19	270.55
520.37	482.65	417.60	360.94	334.31	313.74	292.03	278.35
566.06	521.34	444.43	377.77	347.60	322.61	297.40	281.58
679.62	608.84	497.74	411.60	374.35	346.94	319.25	302.47
Discharge Affected by Freeze-Up							
117.63	109.36	94.60	81.24	74.81	69.78	64.41	61.00
130.20	120.60	103.78	88.87	81.78	76.29	70.45	66.77
145.40	132.85	112.18	95.02	87.28	81.43	75.37	71.63
166.58	149.67	123.27	102.95	94.20	87.78	81.31	77.39
219.18	193.04	153.22	123.47	110.95	101.88	92.86	87.45
2.43	2.13	1.42	0.75	0.48	0.32	0.19	0.12
2.64	2.30	1.54	0.85	0.47	0.39	0.24	0.17
2.88	2.52	1.76	1.06	0.77	0.56	0.38	0.29
3.52	3.04	2.19	1.45	1.04	0.91	0.70	0.58
4.38	3.71	2.71	2.00	1.71	1.50	1.30	1.19
5.73	4.74	3.35	2.65	2.42	2.27	2.15	2.09
14.88	11.26	7.35	5.44	4.86	4.51	4.22	4.08
34.78	30.15	22.34	15.98	13.21	11.21	9.23	8.08
35.32	30.70	22.93	16.58	13.81	11.79	9.79	8.62
37.05	32.06	23.88	17.34	14.52	12.48	10.46	9.26
38.75	34.02	25.89	19.07	16.04	13.80	11.57	10.24
40.95	36.37	28.31	21.33	18.16	15.78	13.37	11.92
44.51	39.55	31.11	24.02	20.83	18.44	16.00	14.53
60.00	52.95	41.74	32.97	29.17	26.38	23.56	21.86
665.59	620.50	541.58	471.55	438.20	412.23	384.63	367.14
684.86	638.95	557.59	484.36	449.15	421.61	392.21	373.52
717.46	669.67	582.61	501.89	462.38	431.19	397.68	376.27
744.48	694.31	604.29	522.20	482.42	451.18	417.74	396.44
776.46	720.76	622.96	536.02	494.61	462.40	428.22	406.59
821.33	758.09	649.64	555.90	512.12	478.42	433.00	420.77
974.49	885.70	738.68	617.07	562.05	520.50	477.57	451.03

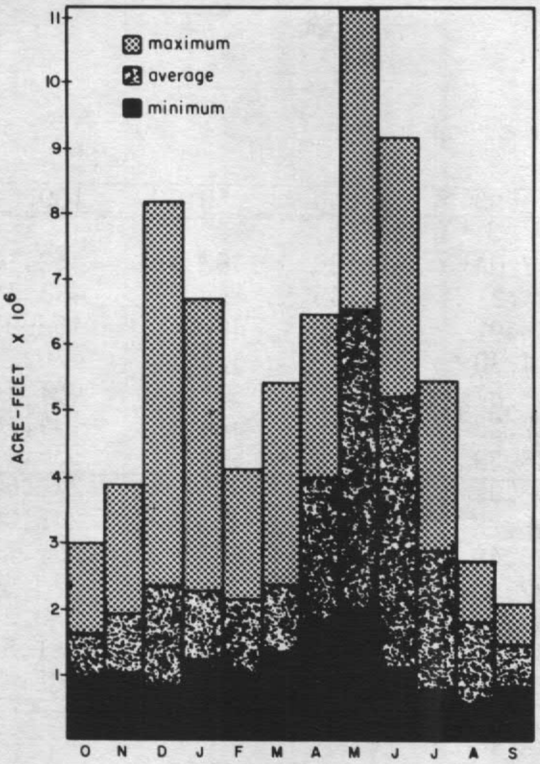

FIGURE 40. Maximum, minimum, and average monthly discharge 1911-1971, Klickitat River near Glenwood, Washington.

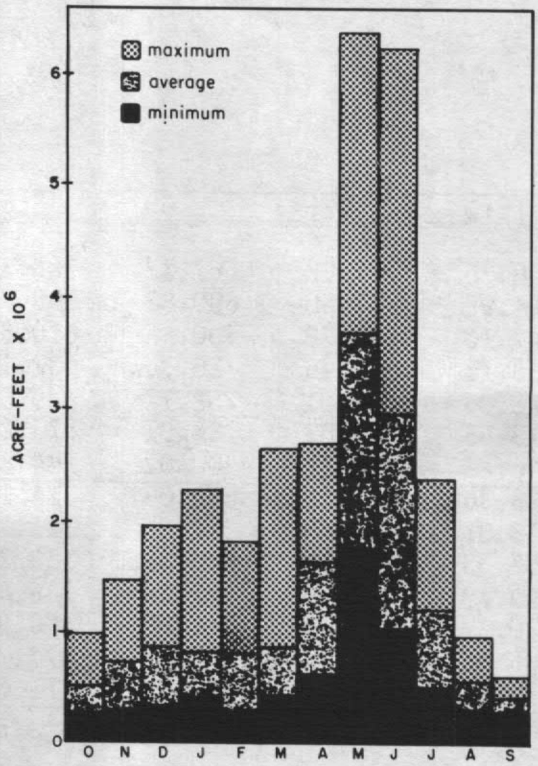

FIGURE 41. Maximum, minimum and average monthly discharge 1945-1975, Klickitat River above West Fork near Glenwood, Washington.

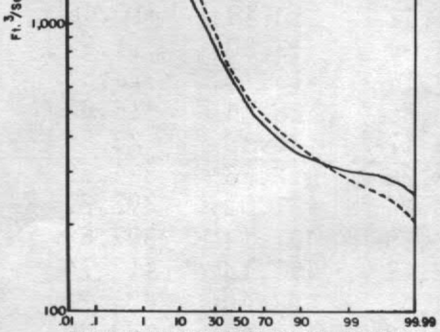

FIGURE 42. Flow duration, Klickitat River near Glenwood, Washington.

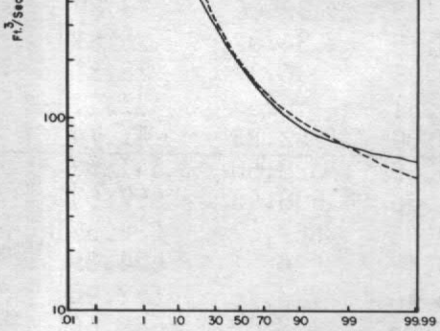

FIGURE 43. Flow duration, Klickitat River above West Fork near Glenwood, Washington.

the river's mouth. This station, which provides an overall picture of the river's characteristics, has been operated continuously since 1928. The records are affected by a major diversion to Hellroaring Ditch mentioned earlier.

As might be expected, information gathered at the Pitt station represents an integration of that described for the Little Klickitat and upper Klickitat basins. Basin runoff (Table 3) is about twice that of the Little Klickitat near Wahkaicus and about half that of the Klickitat River near Glenwood. Similarly, average discharge of the Klickitat River appears to be about half of the average discharge at Pitt. However, a comparison of high flows reveals that discharge of the Little Klickitat near Wahkaicus is more than one third of the peak discharge of the Klickitat River at Pitt.

Comparison of the six-year hydrographs of the Pitt station (Figure 44) with those of the other stations reveals a closer resemblance to flows in the upper basin than those in the Little Klickitat River. However, in many instances, the hydrograph is a composite with marked similarity of selected events apparent in comparison with hydrographs from the Little Klickitat and upper Klickitat basins. Monthly discharges (Figure 46) also represent a combination of conditions from different parts of the basins as maximums reflect the immediate runoff from all areas whereas averages reflect the contribution from snowpack in the upper basin.

Flow duration curves (Figure 47) prepared for the station near Pitt indicate relatively little annual variation and a sustained low flow. Analyses of low flows for all stations on the central Klickitat River reveal that minimum flows at the Pitt station are considerably higher than those in the upper basin. The addition of low flows from the Little Klickitat and other southern drainages cannot account for the difference. Instead, the

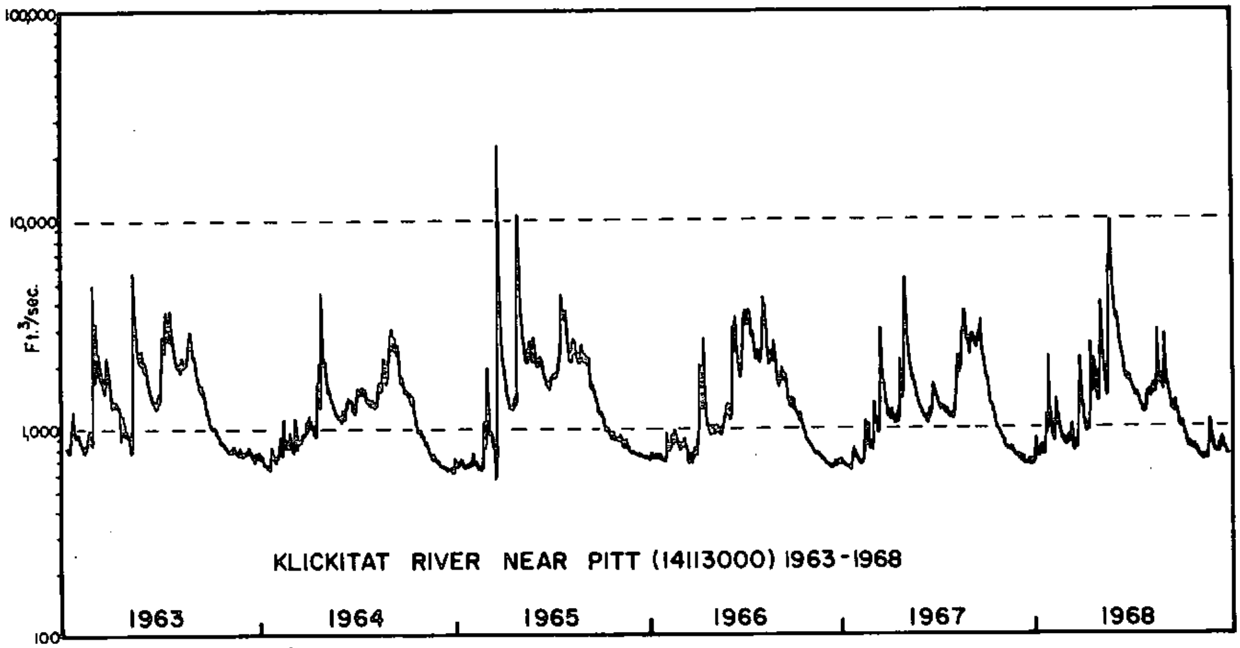

FIGURE 44. Mean daily discharge, Klickitat River near Pitt, Washington.

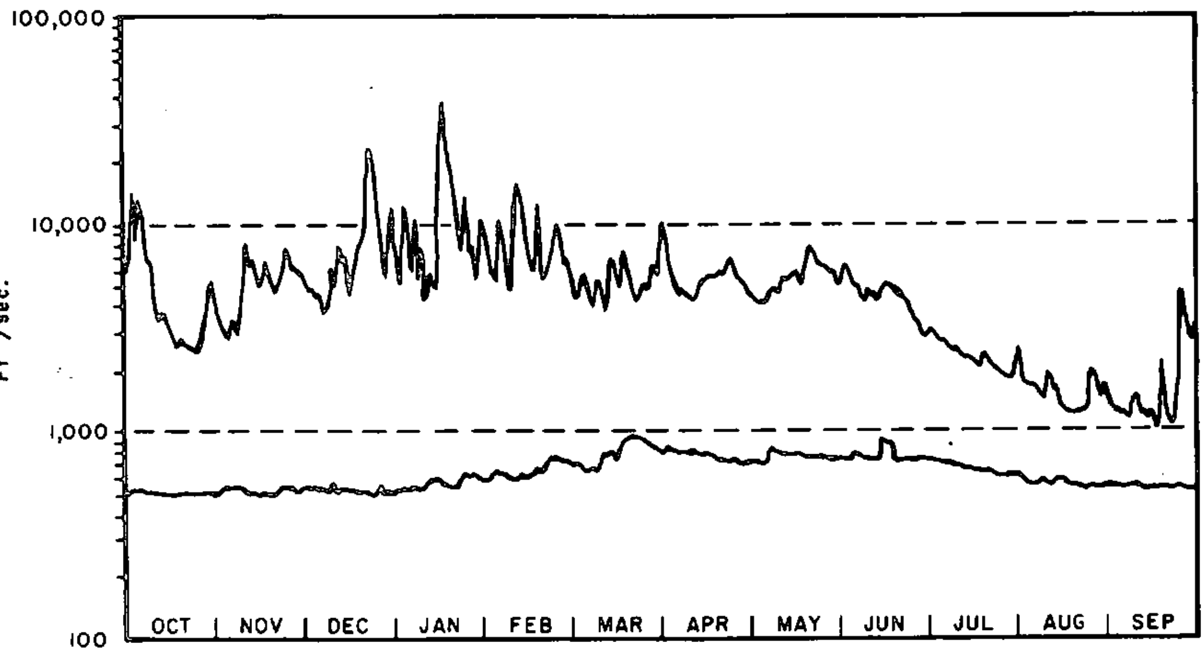

FIGURE 45. Maximum-minimum discharge, 1928-1978, Klickitat River near Pitt, Washington.

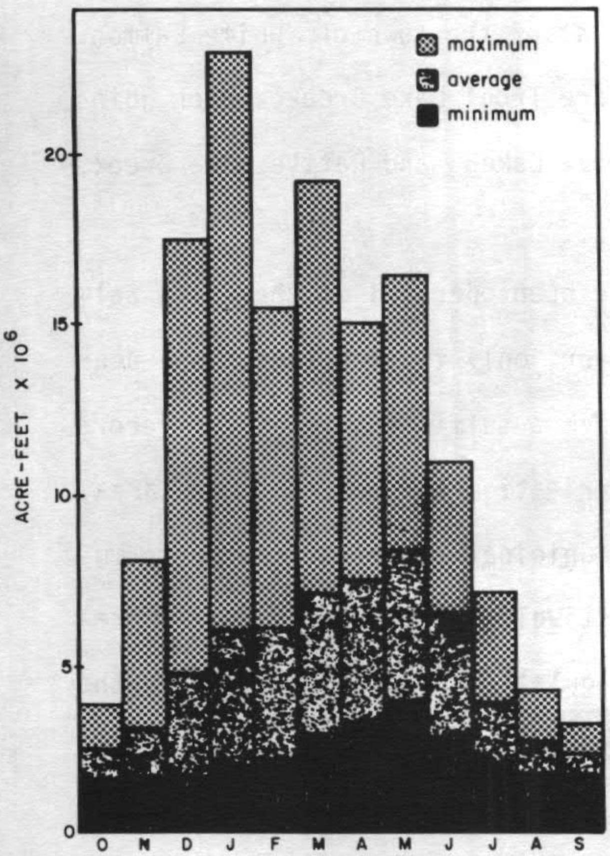

FIGURE 46. Maximum, minimum and average monthly discharge, 1929-1975, Klickitat River near Pitt, Washington.

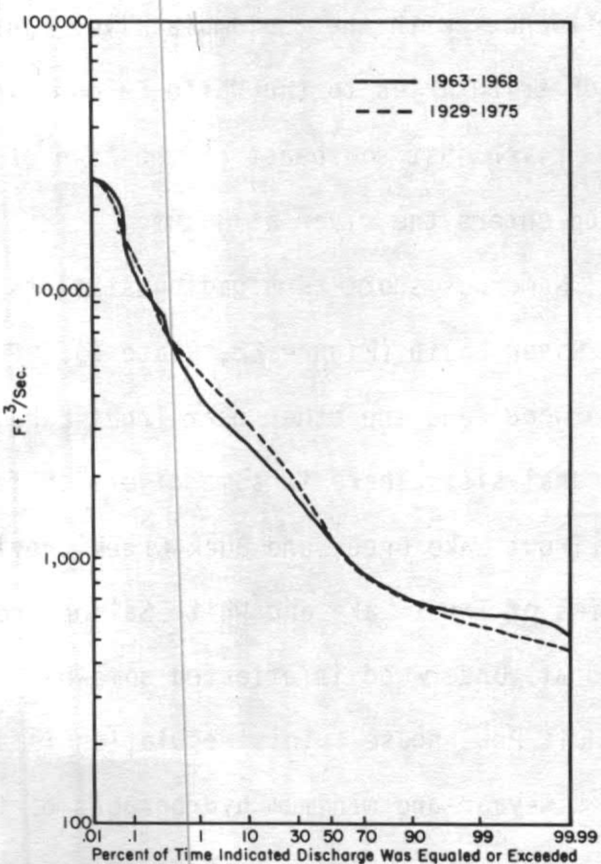

FIGURE 47. Flow duration, Klickitat River near Pitt, Washington.

low flows are attributed to ground-water inflow to the main Klickitat River from several large springs near the northern border of the county.

White Salmon River Basin

Located in the extreme western part of Klickitat County, the White Salmon River drains an area of approximately 385 square miles. Like the Klickitat River, headwaters of the White Salmon River are located on the southern slopes of Mt. Adams. The White Salmon basin exhibits extremely rugged topography and is composed of series of small isolated tributary drainages. From its headwaters, the White Salmon River flows essentially due south to its confluence with the Columbia River just west of the town of White Salmon. Major tributaries to the White Salmon River are Trout Lake Creek, which joins the river just southeast of the town of Trout Lake, and Rattlesnake Creek, which enters the river at Husum.

Numerous short-term gaging stations have been operated in the White Salmon River basin (Figure 22, Plate I). However, only two stations, one near Underwood and the other near Trout Lake, have a sufficient length of record for analysis. There is some diversion for irrigation in the Trout Lake area, and Trout Lake Creek and Buck Creek provide municipal supplies for the communities of Trout Lake and White Salmon, respectively. The gaging station record at Underwood is affected somewhat by regulation being located below the Conduit Powerhouse. This regulation is apparent in the oscillating nature of the six-year and minimum hydrographs of the station.

The White Salmon basin receives precipitation in the form of snow at higher elevations and as rain over the remainder of the basin. Mean annual precipitation in the lower part of the basin is 45-50 inches and increases substantially in higher northern areas.

The effect of relatively high precipitation throughout much of the White Salmon River basin is apparent from a comparison of average annual discharge for this stream with that of the Klickitat River (Table 3). While the drainage area of the White Salmon River is less than one-third of that of the Klickitat River, the average discharge at Underwood is 1140 cfs, compared to 1630 cfs for the Klickitat River at Pitt. The six-year mean daily hydrographs of the two stations on the White Salmon River (Figure 48) reveal only moderate fluctuations in flow, with peak and low flows varying little from the annual mean. Hydrographs for both stations exhibit striking similarities. Direct correlation of individual events is apparent although recession

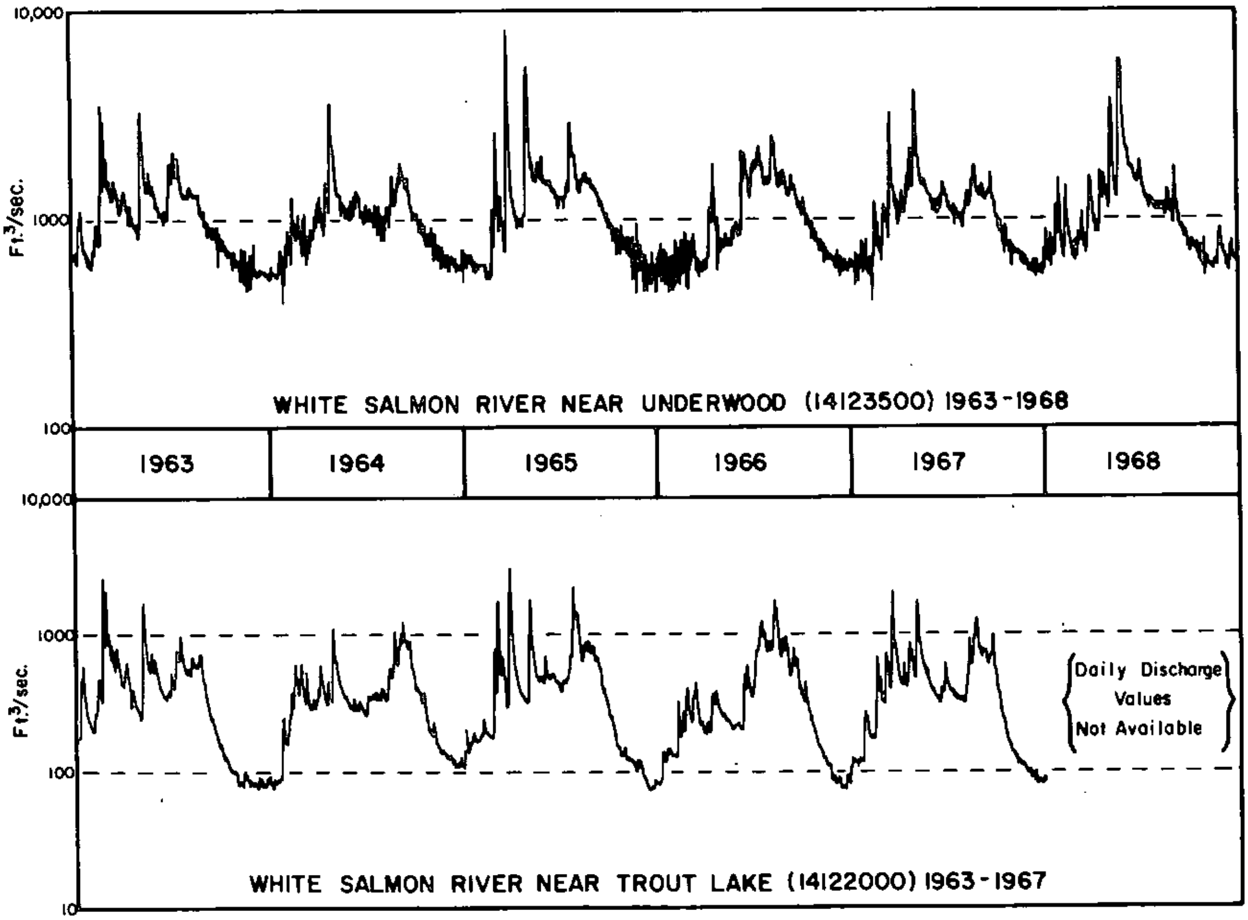

FIGURE 48. Mean daily discharge, White Salmon River, Klickitat County, Washington.

limb slopes reflect the additional contributions to the river from Rattlesnake Creek and a ground-water inflow from a series of springs in the Husum area. A comparison of the six-year hydrographs with those of the upper Klickitat basin reveals a relatively good correlation of events. This similarity is a response to the common source area (Mt. Adams) for both streams and similar basin geography.

The maximum-minimum hydrographs (Figures 49 and 50) and monthly minimums, maximums and means (Figures 51 and 52) for these streams readily show the influence of late spring and early summer snowmelt. Although still

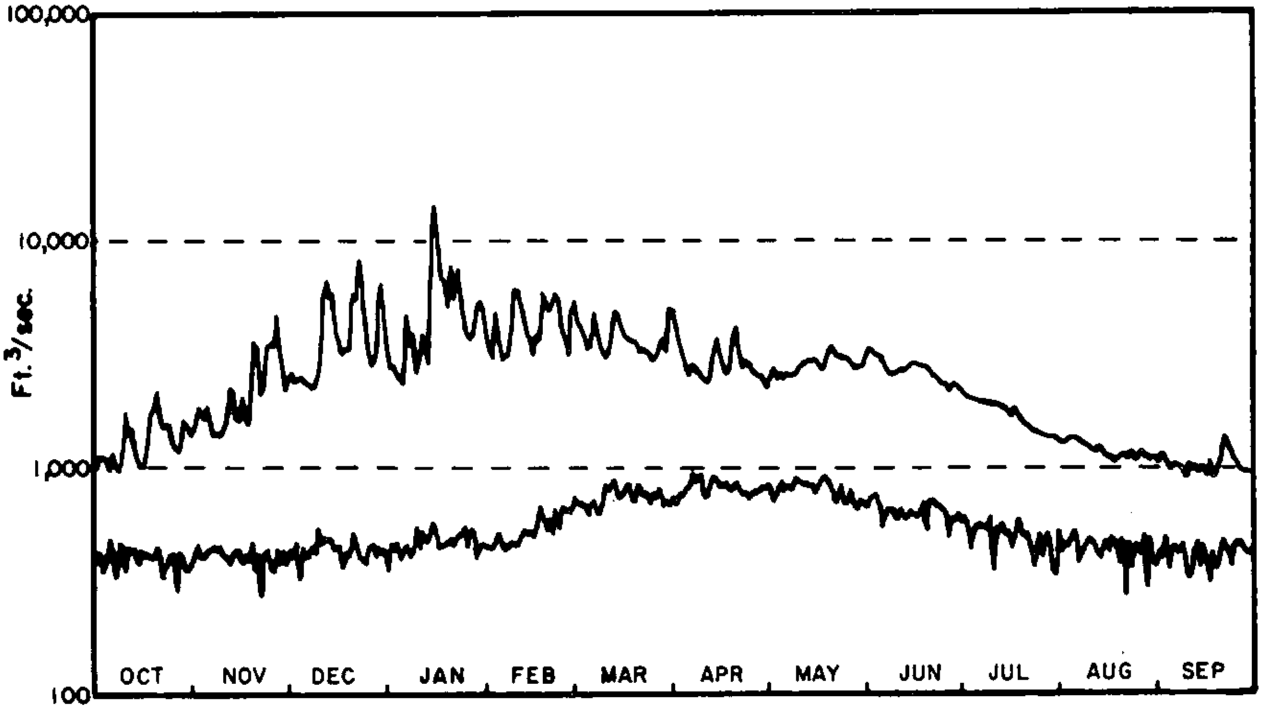

FIGURE 49. Maximum-minimum discharge, 1935-1975, White Salmon River near Underwood, Washington.

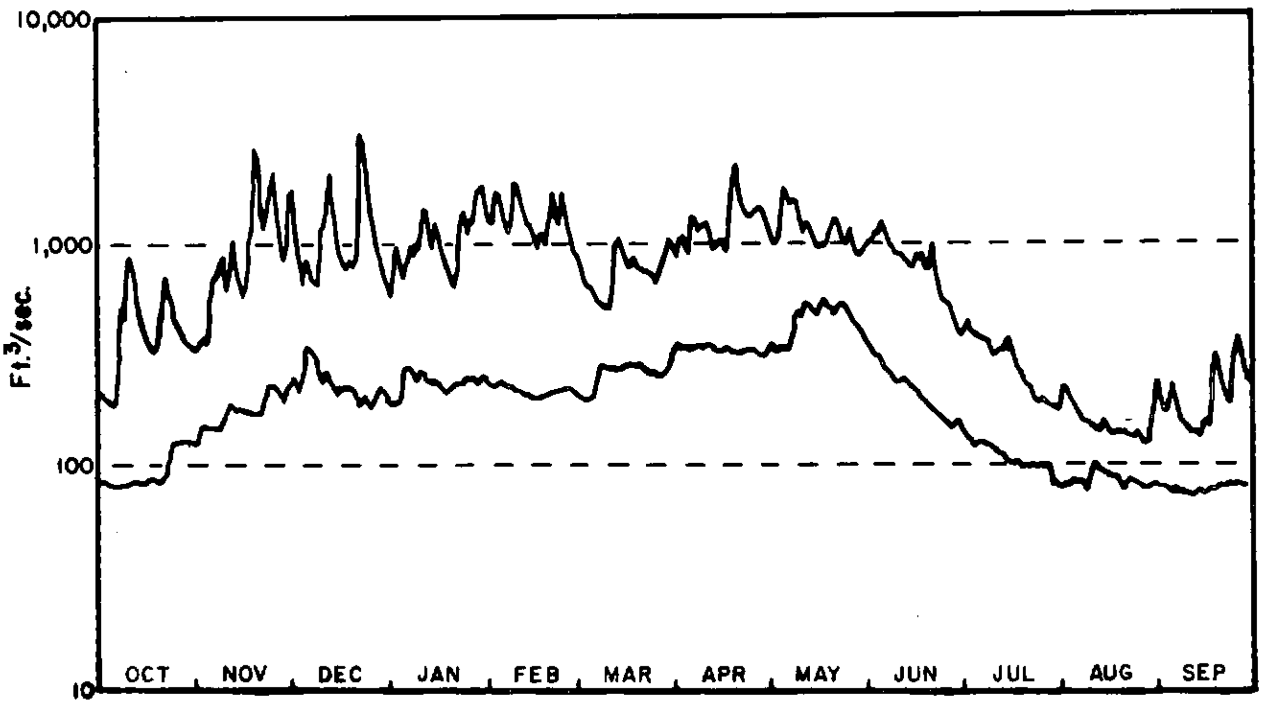

FIGURE 50. Maximum-minimum discharge, 1958-1967, White Salmon River near Trout Lake, Washington.

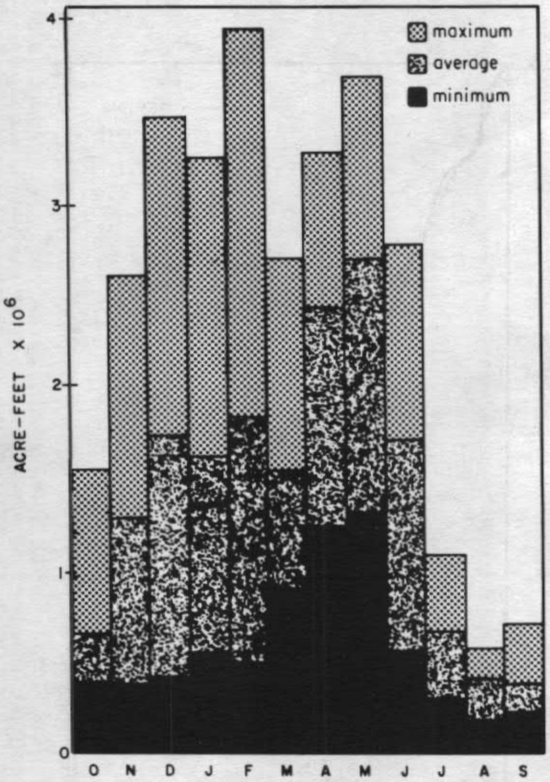

FIGURE 51. Maximum, minimum and average monthly discharge, 1958-1967, White Salmon River near Trout Lake, Washington.

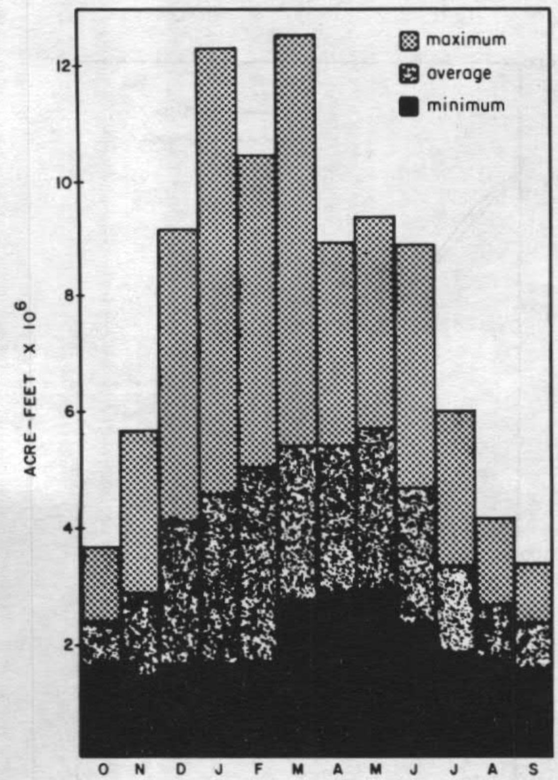

FIGURE 52. Maximum, minimum and average monthly discharge, 1935-1975, White Salmon River near Underwood, Washington.

evident, the effect is less apparent in the White Salmon River basin than in the upper Klickitat. Although some of the snow fields of Mt. Adams feed the White Salmon River, it does not have the large upper drainage development that exists in the Klickitat River basin, and a correspondingly smaller amount of its total flow is derived from melting of snow and ice. It is likely, however, that the White Salmon River derives a greater contribution from ground water than does the Klickitat River.

Flow duration curves (Figures 53 and 54) are very similar in both six-year and period-of-record totals, indicating that discharge variation from year to year is low. The horizontal low-flow part of the curves implies a

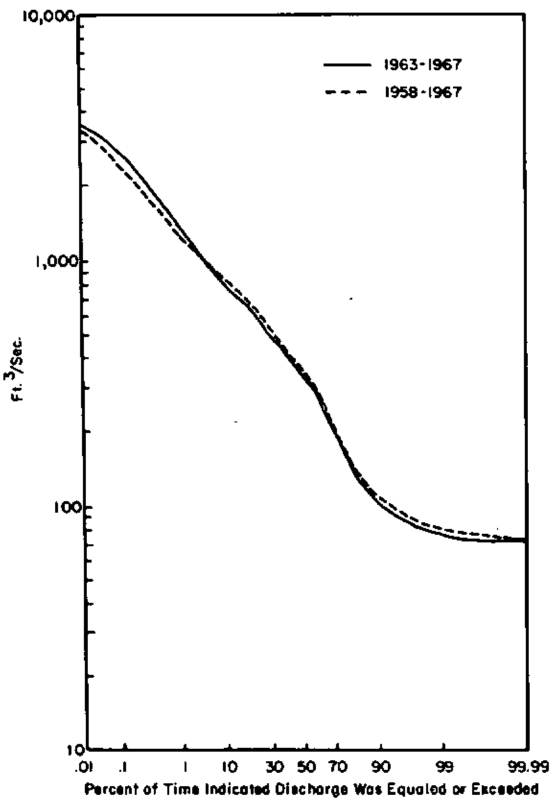

FIGURE 53. Flow duration, White Salmon River near Trout Lake, Washington.

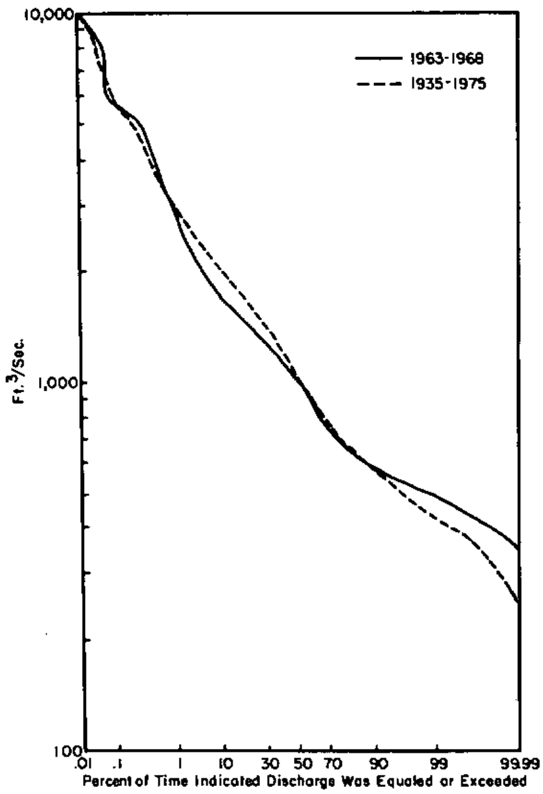

FIGURE 54. Flow duration, White Salmon River near Underwood, Washington.

good sustained flow during low-flow periods which is confirmed in low-flow analysis (Table 4).

Summary

Surface-water hydrology is clearly influenced by the geographical variation present in Klickitat County. Analysis of drainage basin hydrology reveals a gradational change from intermittent streams with highly variable discharges in the east, to perennial streams with relatively constant discharge in the west. Stream flows in the western area are sustained by melting snows and contributions from ground water, while streams in the east flow only in response to direct precipitation runoff. Streams in the central part of the county represent a transition between the two extremes with either very low minimum discharges or a lack of flow during the driest months.

The intermittent nature of surface-water supplies in the eastern half of the county limits their availability for irrigation and other uses. Streams in the west, however, have good sustained low flows and are thus available for use during the entire year.

Floods

Flooding occurs most often during the high runoff months, normally in late winter or early spring. Although flooding is a normal periodic occurrence of most streams, it has significant effects on the cultural modification of flood-prone areas. Hence, information on flood magnitude and occurrence is important to flood plain development and design of flood control projects, bridges, culverts, road beds, and buildings.

While it is presently impossible to predict the time of occurrence of a flood of a given magnitude, flood-frequency analysis can provide an idea of the probability of occurrence of a given size flood in any one year. Flood-frequency analysis is based upon the historical stream discharge record and involves calculation of the interval, in years, during which a certain stream discharge is likely to be equaled or exceeded. With gaging records of sufficient length, flood-frequency curves can be plotted which provide an indication of the recurrence interval of a given discharge within a given time frame.

Figures 55 and 58 are flood frequency curves for selected stations in the Klickitat and White Salmon River drainages. The curves were prepared

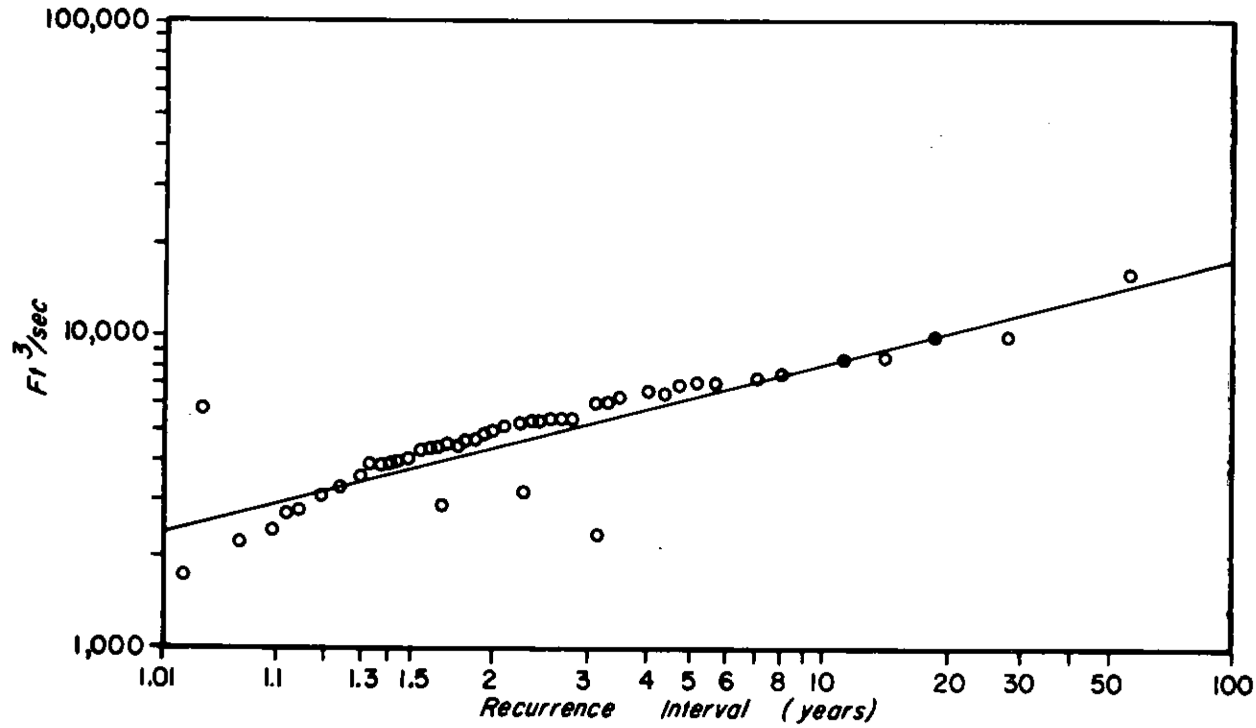

FIGURE 55. Flood frequency, 1916-1975, White Salmon River near Underwood, Washington.

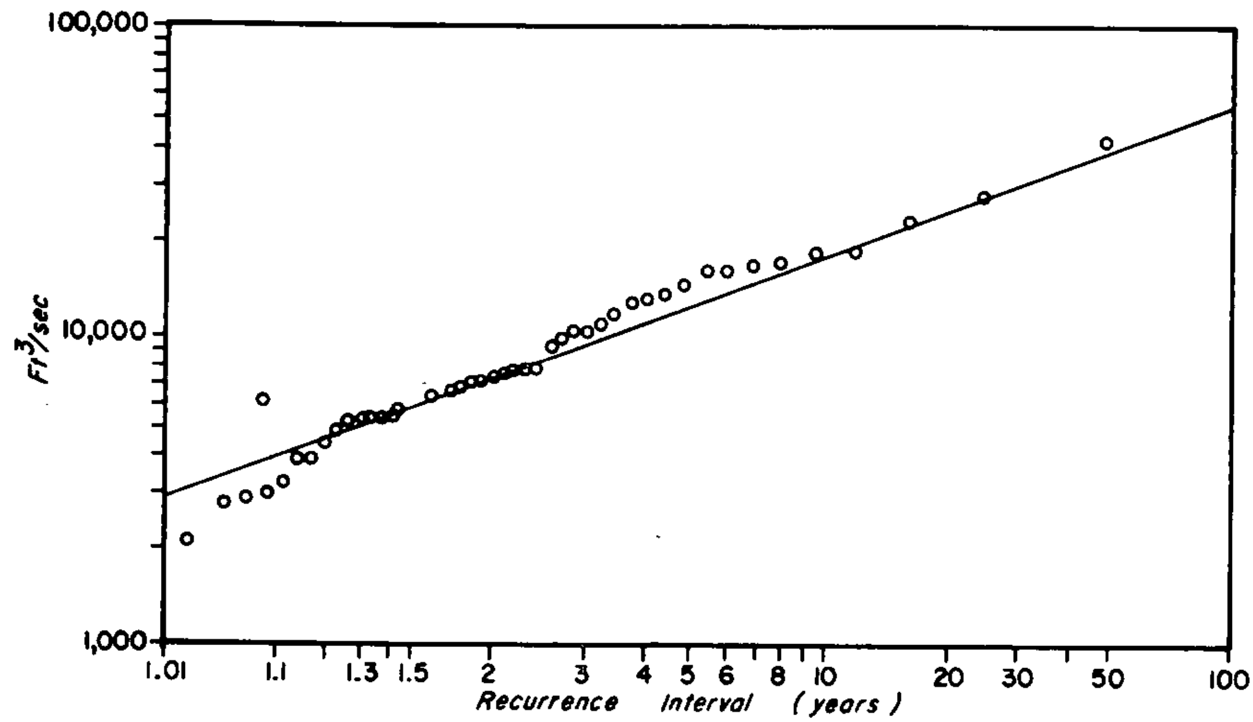

FIGURE 56. Flood frequency, 1929-1975, Klickitat River near Pitt, Washington.

only for those gaging stations in the study area with relatively long periods of record. Peak discharges for many gaging locations within the county and upper Klickitat River basin are presented in Table 3. Information on flood frequencies in Klickitat County is also presented in reports by Cline (1976) and Longfield (1974).

Data Preparation

To obtain the information for Figures 55 through 58, annual peak discharges were first placed in order, from largest to smallest, for the entire period of record for each gaging station. The recurrence interval of each annual maximum was then calculated using the technique outlined by Dalrymple (1960), in which each point is plotted using a log probability scale which tends to make the data plot as a straight line. A line was then fitted to the points to produce the flood-frequency curve. Any point on the line will give the probable recurrence interval of a flood of a given magnitude.

Although the flood-frequency curve is a useful analytical tool, some care must be exercised in its use. Although the curve indicates the recurrence interval, in years, of a flood of given magnitude, it is not possible to predict when a flood of that magnitude will occur. For example, it is possible for two floods with a 100-year recurrence interval to occur in consecutive years or on consecutive days. Futhermore, because the curve is a "best fit" to the data, considerable variation in position of the curve is possible and exists in some of the plots. Since the discharge scale is logarithmic, a change in curve position could have substantial effect on the projected magnitude of a flood at a given recurrence interval. Finally, curves are prepared only for the period of time for which stream gaging information is available, a period which seldom exceeds 50 years in Klickitat

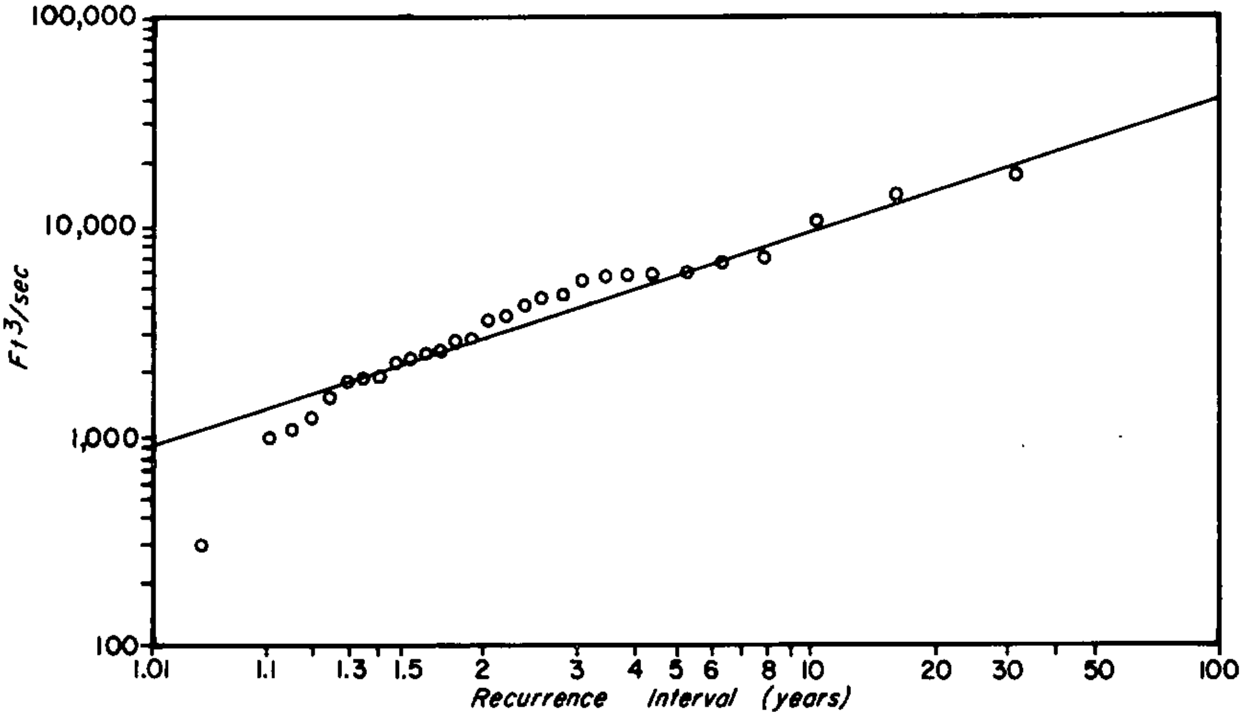

FIGURE 57. Flood frequency, 1948-1975, Little Klickitat River near Wahkaicus, Washington.

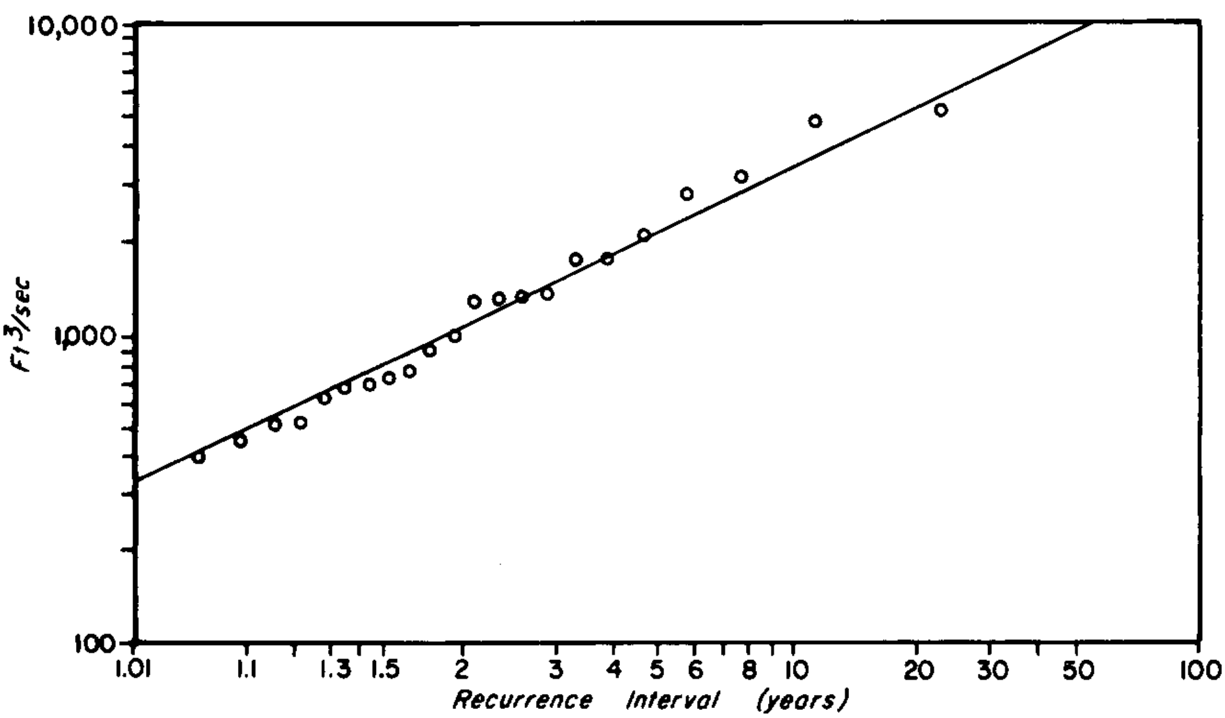

FIGURE 58. Flood frequency, 1947-1975, Little Klickitat River near Goldendale, Washington.

County. Since many drainage basin parameters (vegetation, slope, cultural modifications) are changing, it is unlikely that any past record will be totally representative of a stream's flood characteristics in the future. Despite these drawbacks, a carefully prepared flood-frequency curve for a station with sufficient record can be a valuable hydrologic tool.

Sufficient record for flood-frequency analyses were available only for the White Salmon and Klickitat Rivers. Flood-frequency data for the upper Klickitat River are provided by Cline (1976).

Flood Magnitude and Frequency

Instantaneous discharge maximums for most streams in the western half of the county resulted from the same storm events. Maximum annual floods recorded on the Little Klickitat River near Goldendale were 4,750 cfs on January 16, 1974, and 5,200 cfs on December 23, 1964. Maximum flood flows for the Little Klickitat River near Wahkaicus were 14,500 cfs on January 16, 1974, and 17,300 cfs on December 23, 1964. Figures 55 and 56 suggest discharge maximums of these magnitudes may have recurrence intervals of 30-40 years. Annual flood maximums for the Klickitat River at Pitt occurred at almost the same time as those on the Little Klickitat; however, the relative magnitudes of the events are different. At the station near Pitt, the peak discharge of January 16, 1974, was 47,400 cfs and far exceeded that of December 29, 1964, which was 31,100 cfs. Similarly on the White Salmon River, a maximum discharge of 15,300 cfs was measured at Underwood (see Figure 56) in January 1974. This exceeded by 1-1/2 times the previous high of 9,700 cfs recorded on December 29, 1917. Flood-frequency analyses (Figures 57 and 58) indicate the maximums recorded for these stations have a recurrence interval of 50 to 100 years.

Although annual maximums recorded in 1974 on both the upper Klickitat and the Little Klickitat drainages were well below the historical extremes, the combination of rapid heavy runoff from all areas of the Klickitat River basin produced a very severe flood in January of 1974. This flood was extremely damaging in the lower basin, destroying property, roads and bridges.

Circumstances which produced the 1974 flood are probably similar to those that cause most major flooding in the county. Adequate fall precipitation allowed soils in most areas to reach field capacity. Snowfall during early winter was not excessive, but it was widespread and blanketed both lowland and mountain areas. Furthermore, the snow had a relatively high moisture content (Longfield, 1974). A severe storm system, moving in from the Pacific in mid-January, caused continued precipitation, mainly in the form of rain, for several days. Concurrently, above normal temperatures prevailed with freezing levels rising as high as 8,000 feet. The combination of steady precipitation and saturated or frozen soils produced widespread runoff. The runoff was uniform in that it came from virtually all areas of the drainage basin and produced extremely high flows in lower reaches of the streams.

While stream flow records were insufficient to prepare flood-frequency curves for streams in eastern Klickitat County, an estimate of the order of magnitude of annual floods for Rock and Alder Creeks can be obtained from the maximum hydrographs (Figures 24 and 27) from Table 3, and from crest-stage measurements (Table A-3, Appendix A). Examination of these data indicate that conditions of late December 1964 produced very high flood flows in both Alder Creek and Rock Creek. Table 3 reveals that, although basin runoff is low for streams in eastern Klickitat County, maximum discharge of these streams exceeds that of others with greater drainage area to the west. These data verify the "flashy" nature of streams in eastern Klickitat County and suggest a high potential for flash flooding in these basins.

All drainage basins within the county have generally steep slopes which can produce rapid runoff and serious floods. This potential must be considered in planning any development or use of flood-prone areas within the county.